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A STUDY OF THE RAIN EROSION OF PLASTICS AND METALS

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FEBRUARY 1954

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WRIGHT AIR DEVELOPMENT CENTER

NOTICES

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Cornell Aeronautical Laboratory, Inc.

February 1954

Materials Laboratory
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Wright Air Development Center
Air Research and Development Command
United States Air Force
Wright-Patterson Air Force Base, Ohio

McGregor & Werner, Inc., Dayton, Ohio
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FOREWORD

This report was prepared by the Cornell Aeronautical Laboratory under USAF Contract No. AF 33(600)-6469. The contract was initiated under Research and Development Order No. 614-12(B-F), "Structural Plastics", and was administered under the direction of the Materials Laboratory, Directorate of Research, Wright Air Development Center, with Mr. George P. Peterson acting as project engineer.

ABSTRACT

Based upon data obtained in studies of the relative rain erosion resistance of various types of materials, the general requirements needed for maximum erosion resistance can be quantitatively met by two properties which are the antithesis of each other. One; a relatively soft, tough, smooth elastomeric material and two; a hard, smooth, ductile material with high compressive strength. The first is typified by neoprene coatings such as Gaco N-79 and Goodyear 23-56. The second, by titanium and tough alloy steels such as 4130.

To further define these requirements, studies of various materials were continued.

Proposed tests and materials to be evaluated at Mach numbers above two, are discussed.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

M. E. SORTE
Colonel, USAF
Chief, Materials Laboratory
Directorate of Research

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

LIST OF TABLES (CONT'D)

OBJECTIVE

Erosion, by rain, of the exterior surfaces of high speed aircraft during flight gives rise to a new problem in aircraft materials. This study was undertaken to obtain data on currently used aircraft materials and to investigate the phenomena of rain erosion in order that the increased fundamental knowledge might be used to assist in the development of materials more resistant to deterioration.

INTRODUCTION

One of the problems facing the designer of high speed aircraft is the problem of rain erosion of aircraft components. Previous studies and their results have been reported. (references 1, 2, 3, 5, 7, 9, 10, 11, 13, and 14).

The erosive effect of rain on high speed aircraft has not been limited to paint coatings or glass reinforced plastic parts. The reports noted above indicate that when subsonic aircraft fly through a rainstorm, the water drops erode the leading metal edges in such a manner that the surface appeared as though it had been sandblasted. It is to be noted, however, that the erosion of most metals is less severe than plastics.

Previous work carried out under the guidance of the Wright Air Development Center included the development of testing methods in which flight in rain was simulated and in which erosion characteristics of plastic were evaluated. Many different plastics and coatings were tested.

The problem of obtaining materials which will resist erosion for long periods of flight through rain is still under investigation. Evaluation tests of materials under simulated high speed flight through rain have not been satisfactory in that they reveal few materials likely to withstand rain erosion for any appreciable length of time. In order to aid in the development of a satisfactory material, a study of the mechanism of some of the problems and characteristics especially pertinent to rain erosion in the hope that increased knowledge may serve as a guide both in the search for, and design of, better materials.

SECTION I

EVALUATION OF MATERIALS

In this investigation, all the tests were carried out in one inch per hour rainfall concentration, having a medium droplet size of 1.9 mm. and at speeds of 500 mph or above, on the test apparatus which consists of a set of blades that rotate at speeds ranging from 500 to 750 mph in a horizontal plane through simulated rainfall. Test specimens of airfoil shape, shown in Figure 1, are attached to the blade. Specimens may be of plastic or metal and may be tested with or without coatings. The details of test apparatus are reviewed in a Wright Air Development Center report (reference 15).

The nominal velocities given herein refer to the center of the specimen. If the time to erode through the coatings, at 500 mph and 1" per hour rainfall, outlined in this report appear to be lower on some specimens than previously reported, it should be remembered that the time of test obtained on this new erosion test apparatus must be multiplied by 1.6 to obtain a comparison with former data.

It is realized the test apparatus does not exactly reproduce the amount of erosion experienced during the same time interval as one obtains under actual service conditions. However, it has been shown that it does rate materials in the relative order of their service durability.

Glass reinforced plastic parts cannot be ruled out as a material of construction since it is necessary that radar equipment be placed in non-metallic housings which maintain the smooth, exterior contours of high speed aircraft. Methods of rendering these glass laminates more resistant to rain erosion, by coating with organic materials, were studied extensively.

IA. Neoprene Coatings

Previous data have shown that of all the materials tested, neoprene possessed greater erosion resistance at 500 mph, than any other plastic or elastomeric coating. The two neoprene coating materials that have shown the most promise, to date, are Gaco Aircraft Neoprene Coating N-79 and Goodyear Aircraft Neoprene Coating 23-56. Other similar coatings have been evaluated and the tests are outlined in this report.

Gaco and Goodyear neoprene coatings when catalyzed with the proper amount of catalyst will air dry, however, none of these coatings attain full strength and rain erosion resistance properties until they have cured at room temperature in excess of 100 hours. Most all of the neoprene coatings require primer coats for

adhesion to plastic or metal. In most cases, the primer used was Bostik 1007, manufactured by B. B. Chemical Company, Cambridge, Mass. These coatings and primer can be applied by brushing or spraying. Brushing gives heavier but less uniform coats.

The following procedures are recommended by the manufacturer of these coatings and they were followed in the preparation of all test specimens. Gates and Goodyear have available for distribution Wright Air Development Center approved instructions sheets as to detail procedure for preparing and applying coatings approved under specification MIL-C-7439.

Gaco N-79 System - Air Drying

1. Roughen metal or glossy resin surface with 80 grit sandpaper and wipe clear with toluol.
2. Apply one brush coat of Gaco or Bostik primer and air dry at least 30 minutes, or two spray coats of Gaco Primer N-15 or Bostik 1007.
3. Catalyze N-700-9 cement by adding Gaco Accelerator N-300-9 in ratio of one fluid ounce of accelerator to one pint of cement and mix thoroughly.
4. Apply five brush coats of accelerated Gaco N-700-9, using short, even strokes and brush from wet to dry areas to prevent trapping air in coating, or eight to twelve spray coats.
5. Allow at least one hour air dry between coats.
6. The curing cycle of specimens was 100 hours air drying before testing.

Goodyear 23-56 System - Air Drying - Brush or Spray

1. Roughen the metal or smooth resin surface of the glass laminate specimen with 80 grit paper.
2. Apply two spray coats of Bostik 1007; allow to air dry 30 minutes.
3. Add 8.5 cc. of accelerator 983C to each 100 grams of 1801C base cement and mix thoroughly for five minutes.
4. The 23-56 brush coating is applied without reducing. Normally, five brush coats are applied to achieve a 10 mil coating, air drying 45 to 60 minutes between coats. All coats are applied within an eight hour period.
5. After accelerating, the 23-56S spray coat is reduced with an equal volume of 23-56S thinner supplied by Goodyear. Normally, with this reduction, 8 to 12 spray coats are required.
6. All specimens are allowed to air dry at least 100 hours before testing.

Four glass reinforced laminate panels of Selectron 5003, 116-114 glass cloth, .030" x 18" x 18" were exposed at 45° facing south on the roof at Cornell Aeronautical Laboratory for one year. Panel #1 was not coated and was used as a control. The coatings consisted of the systems outlined below and were 10 mils in total thickness. Microscopic examination at 12X showed that all films were cracked or checked during the year's exposure.

TABLE NO. 1
Outdoor Exposure Tests Of
Neoprene Coatings

Panel No.	Primer	Top Coat	Macroscopic Examination After 1 Year Exposure
1	None	None	Slight yellowing of Selectron 5003. No other visual changes.
2	Bostik 1007	Gaco N-79	Fine hairline cracks through coating. Film turned reddish brown.
3	Primer 3M-EC 579 Tiecoat - 3M-Exp. 127735	3M-Exp.127736	Considerable alligatoring and large checking through film.
4	Bostik 1007	Goodyear 23-56	Alligatoring and small checking through film. Film turned black.

Based upon a visual and macroscopic examination, the durability of the films, after one year's outdoor exposure, could be rated in the following order.

1. Gaco N-79
2. Goodyear 23-56
3. 3M - Exp. 127736

The four panels were returned to Wright Air Development Center for determination of the electrical properties.

Twenty-three rain erosion test specimens were returned from Wright Air Development Center after outdoor exposure in Florida for six months and for one year. They were identified as follows:

I. 1 year exposure (29 November 1950 - 29 November 1951)

(1) Specimen No. 561 A & B - 7 spray coats of Goodyear 23-56 over 2 spray coats of Bostik 1007. Coated by Wright Air Development Center.

(2) Specimen No. 562 A & B - Brush coats of N-200-5E over 2 spray coats of Bostik 1007. Coated by Wright Air Development Center.

II. 6 months exposure (29 May 1951 - 29 November 1951)

(1) Specimen No. 344 A & B and 345 A & B - Spray coated with Goodyear 23-56-S by Goodyear.

(2) Specimen No. 342 A & B and 343 A & B - Brush coated with Goodyear 23-56 by Cornell.

(3) Specimen No. 338 A & B and 339 A & B - Spray coated with 3M EC-579 primer, Exp. 127735 tie coat and Exp. 127736 top coat, by Cornell.

(4) Specimen No. 336 B and 337 A & B - Spray coated with Gaco N-700-9 (N-300-11 accelerator) by Wright Air Development Center.

(5) Specimen No. 340 A & B and 341 A & B - Brush coated with Gaco N-200-5E by Cornell.

These specimens were all tested for rain erosion resistance at 500 mph and 1" per hour rainfall.

Specimens #561 A & B of Goodyear 23-56 turned greyish black and had alligatored badly after one year's exposure. The rain erosion resistance had deteriorated to practically nothing. Specimens #562 A & B of Gaco N-200-5E showed some yellowing and slight alligatoring after one year's exposure. The weathering had reduced the rain erosion resistanceof the 5 mil coat to less than one minute. Of the specimens exposed for six months, only the brush coated Goodyear 23-56 maintained any appreciable rain erosion resistance. The results obtained are outlined in Table No. 2 and 3.

Specimens #479 A & B, brush coated with Bostik 1007 primer and Gaco N-700-9 neoprene with 12 oz/gal. Gaco N-300-11 accelerator, were exposed on the roof at C.A.L. at Buffalo, New York, for 6 months, October 1951 through April 1952 and then tested at 500 mph. Coating on Specimen B failed at the end of 30 minutes of testing while coating on specimen A bubbled and ruptured at the end of 40 minutes.

Specimens #533 A & B, brush coated with Bostik 1007 and Gaco N-700-9 (pigmented - blue) with 8 oz/gal Gaco N-300-9 accelerator, were outdoor exposed at Buffalo, New York, for 3 months, January 2nd to April 2nd, 1952, and then tested at 500 mph. Specimen A failed at the end of 40 minutes of testing and specimen B failed at the end of 70 minutes.

Specimens #534 A & B, brush coated with Bostik 1007 and Gaco N-79 were outdoor exposed for 3 months, January 2nd through April 2nd, 1952, at C.A.L., before testing. The coating on specimen A bubbled and ruptured after 60 minutes of testing while specimen B bubbled after 70 minutes.

Outdoor durability tests for one year were carried out on Goodyear 23-56, brushed and sprayed, for comparison. Specimens #419A and 422B were prepared at Goodyear by their personnel. Specimen #419 was brushed and #422 was sprayed in the regular production set-up at Goodyear. The samples were sent to Cornell Aeronautical Laboratory and exposed for one year on the roof and then tested at 500 mph and 1"/hr. rainfall. Specimen #419 had considerable better rain erosion resistance than specimen #422, which may be accounted for by the fact that the sprayed film was approximately 20% thinner, however, it has been generally found that the brushed coates of both Gaco N-79 and Goodyear 23-56, for the same thickness of film, had greater rain erosion resistance than the sprayed coats.

Specimens #487 A & B were prepared with Goodyear 23-56 and Goodyear Antistatic coating R-14L-296 and exposed for one year. The antistatic coating was applied two days after the application of the Goodyear 23-56 neoprene coating. After one year's exposure, the antistatic R-14L-296 coating showed no loss of adhesion to the 23-56 but upon testing at 500 mph and 1"/hr. rainfall, the layers showed a tendency to shred off in small areas after 60 to 70 minutes. On normal application of the antistatic coating, it would erode off rather than shred or peel. The specimens #487 A & B showed excellent rain erosion resistance, which can be attributed to two causes; one, the thickness of the coatings, which was a total of 13 mils and the possibility that the antistatic coating protects the 23-56 from weathering since the carbon black tends to improve the outdoor durability.

Specimens #536 A & B of Bostik 1007 primer with Gaco N-79 were prepared and exposed for one year and then tested at 500 mph and 1"/hr. rainfall. These specimens were run to check previous data on Gaco N-79.

Specimens #416 and 420 of Goodyear 23-56 using Bostik 1007, both brush and spray, prepared in the shop at Goodyear Aircraft were exposed outdoors at Buffalo, New York for three months. Specimens #535 of Gaco N-79, prepared by C.A.L. personnel and brushed on, were exposed for six months. Specimens #554 of Goodyear 23-56 and #551 of Gaco N-700-9 with 8 oz/gal N-300-9 catalyst, using new Bostik primer 4764-27, were exposed for three months. In general, specimen #416 A, which was brushed, had slightly better rain erosion resistance than specimen #420 B, which was sprayed. This concurs with previous results obtained. The results are shown in bar graphs on pages 104 and 105, in Table No. 4 and Figure No. 2.

Preparation of Specimens For Outdoor Exposure by FPL

As requested by the Materials Laboratory of Wright Air Development Center, one hundred and eighty rain erosion test specimens of glass fabric reinforced laminates were molded. These specimens were fabricated of 116-114 glass cloth impregnated with Selectron 5016. They were wet sanded with 320 grit sandpaper to roughen the resin surface, given one heavy brush coat of Bostik 1007, and then coated with the following neoprene top coats, so as to give a total thickness of primer and coating of approximately ten mils.

1. Sixty specimens #700 A & B through 729 A & B coated with Goodyear 23-56 system. (Approved under specification MIL-C-7439)

2. Sixty specimens #730 A & B through 759 A & B coated with Gates N-79 system. (Approved under specification MIL-C-7439)

3. Sixty specimens #760 A & B through 789 A & B coated with 6-7 mils of Goodyear 23-56 and 2 mils of Goodyear Antistatic Coating R-14L-23-296.

These samples were then submitted to the Forest Products Laboratory for outdoor exposure at five different exposure stations. It is planned that at the end of exposure periods of three months, one year, and three years, four samples of each group, 1, 2, and 3, will be evaluated for rain erosion resistance at 500 mph and 1"/hr. rainfall.

Evaluation of Gaco Systems

As required under specification MIL-C-7439A class I, the Gaco system of N-15 primer and N-79 top coat was evaluated for rain erosion resistance. The tests on Gaco N-51 anti-static system are described in the next section. The glass reinforced laminates were sanded, wiped with toluol and given two brush coats of Gaco N-15 primer. The specimens were numbered and prepared for the tests, as listed below.

The following seven sets of tests specimens of glass reinforced laminates were coated with 2 mils Gaco N-15 primer and approximately 7-8 mils of Gaco N-79. These specimens were prepared by brushing.

Specimen No.	Tests
664 A & B 665 A & B	Rain Erosion Tests - 500 mph and 1"/hr.
669 A & B 670 A & B	Rain Erosion Tests - 500 mph and 1"/hr. after exposure to 200°F for 20 hours
666 A & B	Outdoor Exposure - 3 months
667 A & B	- 6 months
668 A & B	- 12 months

Erosion tests at 500 mph and 1"/hr. rainfall were carried out on specimens #664 and 665 after air drying for 150 hours at room temperature. Specimens #669 and 670 were air dried 150 hours at room temperature and then exposed to 200°F for 20 hours as outlined in MIL-C-7439, then evaluated for rain erosion resistance under standard conditions as noted above. The specimens of the air dried coatings, after testing, are shown in Figure No. 3. The results of the tests are shown in the bar graph on page 106, and in Table No. 5 on pages 18 through 21. Specimens #666 and 667 and 668 were placed outdoors at 45° facing south. These specimens will be exposed for the periods noted above and then evaluated for erosion resistance under standard conditions. Electrical transmission tests under specification MIL-C-7439A (reference 15) will be conducted on panels coated with these systems.

If these materials have satisfactory electrical properties they should be approved.

TABLE NO. 2
Rain Erosion of Neoprene Coatings
500 M.P.H. - 1"/Hr. Rainfall
Specimens Outdoor Exposed For 1 Year
On Florida Test Fence

Specimen No.	Coated By	Primer	Top Coat	Thickness Coating (Mils)	Time To Erode Thru Coating	Total Time Of Exposure	Remarks
561 A	A.M.C. (#800A)	Bostik 1007	Goodyear 23-56 (Spray) 7 coats	5	1 min.	3 min.	At end of 3 min. - Spec. A Small hole through coating at high speed end and one in center of leading edge. Spec. B - Small holes through coating and 3-5 plies all along leading edge.
B	(#800B)					3 min.	
562 A	A.M.C. (#801A)	Bostik 1007	Gaco N-200-5E (Brush)	5	1 min.	1 min.	At end of 1 min. - Eroded through coating and 2-3 plies at high speed and at low speed ends of leading edge.
B	(#801B)					1 min.	

TABLE NO. 3
Rain Erosion of Neoprene Coatings
500 M.P.H. - 1"/Hr. Rainfall
Specimens Outdoor Exposed For 6 Months
On Florida Test Fence

Specimen No.	Coated By	Primer	Top Coat	Thickness Coating (Mils)	Time To Erode Thru Coating	Total Time Of Exposure	Remarks
336 B	A.M.C.	Bostik 1007	Gaco N-700-9 (N-300-11) (Spray)	8	-	1 min.	At end of 1 min. - Scattered erosion through 1-2 plies along entire leading edge.
337 A	A.M.C.	Bostik 1007	Gaco N-700-9 (N-300-11) (Spray)	8	1 min.	3 min.	At end of 3 min. - Eroded through coating and 5-6 plies along entire leading edge.
B							
338 A	C.A.L.	Primer EC 579 Tie Coat Exp.127735	Exp.127736	10	8 min.	20 min.	At end of 8 min. - Spec. A - Eroded through coating at high speed end of leading edge. At end of 15 min. - Spec. B - 3/16" D hole through coating at high speed end. At end of 20 min. - Spec. A - Eroded through 8-10 plies for 3/4" to high speed end. Spec. B - 3/16" D hole through 15-20 plies at high speed end. 1/16" D hole 1/2" from low speed end.
B					15 min.	20 min.	
339 A	C.A.L.	Primer EC 579 Tie Coat Exp.127735	Exp.127736	10	10 min.	10 min.	At end of 5 min. - Spec. B - Coating bubbled at high speed and at low speed end. At end of 10 min. - Spec. A - Coating bubbled and ruptured at high speed end. Spec. B - Bubbled along entire leading edge. Eroded through 8-10 plies at high speed end and at low speed end.
B					5 min.	10 min.	

TABLE NO. 3 (CONT.)

Specimen No.	Coated By	Primer	Top Coat	Thickness Coating (Mils)	Time To Erode Thru Coating	Total Time Of Exposure	Remarks
340 A	C.A.L.	Bostik 1007	Gaco N-200-5E	10	3 min.	5 min.	At end of 3 min. - Spec. A - Coating bubbled at high speed end. At end of 5 min. - Coating bubbled for 1" of leading edge to high speed end. Eroded through coat and 1 ply for 1/4" to high speed end. At end of 9 min. - Spec. B - Bubble 1/16" D at high speed end and in center of leading edge.
B							
341 A	C.A.L.	Bostik 1007	Gaco N-200-5E	10	5 min.	9 min.	At end of 5 min. - Spec. A - Coating bubbled for 3/4" of leading edge to high speed end. At end of 9 min. - Spec. A - Eroded through 5-7 plies for 1" to high speed end. Spec. B - Coating bubbled and ruptured at high speed and at low speed ends.
B					9 min.	9 min.	
342 A	C.A.L.	Bostik 1007	Goodyear 23-56 (Brush)	10	45 min.	75 min.	At end of 45 min. - Spec. A - Pin hole through coating $\frac{1}{4}$" from high speed end. At end of 60 min. - Spec. B - 2 pin holes through coating at high speed end. At end of 75 min. - Spec. A - 3 bubbles 1/8" D hole at low speed end, through 5-10 plies at high speed end - 3 small holes. Spec. B - Bubbled and $\frac{1}{4}$" hole through 8-10 plies at high speed end.
B					60 min.	75 min.	

TABLE NO. 3 (CONT.)

Specimen No.	Coated By	Primer	Top Coat	Thickness Coating (Mils)	Time To Erode Thru Coating	Total Time of Exposure	Remarks
343 A B	C.A.L.	Bostik 1007	Goodyear 23-56 (Brush)	10	30 min.	40 min.	At end of 30 min. - Spec. A - Bubble 3/4" x 1/8" at low speed end. Spec. B - Bubble 1/2" long at low speed end. At end of 40 min. - Spec. A - Eroded through bubbles and 1 ply of cloth at high speed and low speed ends. Spec. B - Eroded through bubbles, coating, and 5-10 plies at high speed and low speed ends.
344 A B	Goodyear (#S21) (#S22)	Bostik 1007	Goodyear 23-56S (Spray)	10	-	9 min. 9 min.	At end of 9 min.-Spec. A - Coating bubbled - Eroded through coat and 8-10 ply of 181 cloth along most of leading edge. Spec. B - Eroded through coating and 3-5 plies for 1/2" at high speed and low speed ends.
345 A B	Goodyear (#S23) (#S24)	Bostik 1007 1007	Goodyear 23-56S (Spray)	9	1 min. 1 min.	3 min. 3 min.	At end of 1 min. - Coating bubbled at high speed end. At end of 3 min. - Eroded through coating and 2-3 plies for 1/4" to high speed end.

TABLE NO. 4
Rain Erosion of Coatings
500 M.P.H. - 1"/Hr. Rainfall
Outdoor Exposure Tests on Neoprene Coatings

Specimen No.	Primer	Topcoat	Outdoor Exposed	Thickness Coating (Mils)	Time To Initiate Erosion	Time To Erode Thru Coating	Total Time of Exposure	Remarks
419 A	Bostik 1007	Goodyear 23-56 (Brush)	1 yr.	10	20 min.	50 min.	100 min.	At end of 20 min. - Light pitting along high speed end of leading edge. At end of 50 min. - Pin hole through coating. At end of 85 min. - 1/16" D hole eroded through laminate at low speed end. Small hole through coating at high speed end of leading edge. At end of 100 min. - 1/8" D hole through laminate at low speed end. Eroded through coating and several plies in 5 small holes at high speed end of leading edge.
422 B	Bostik 1007	Goodyear 23-56 Spray	1 yr.	8	15 min.	17 min.	20 min.	At end of 15 min. - Small bubble 1/2" from high speed end. At end of 17 min. - Eroded through lifted coating. At end of 20 min. - Eroded through coating and several plies for 1/2" of leading edge to high speed end.

TABLE NO. 4 (CONT.)

Specimen No.	Primer	Topcoat	Outdoor Exposed	Thickness Coating (Mils)	Time To Initiate Erosion	Time To Erode Thru Coating	Total Time Of Exposure	Remarks
487 A	Bostik 1007	Goodyear 23-56 (6 Brush coats) Goodyear R14L-296 (2 brush coats)	1 yr.	13	30 min.	110 min.	150 min.	At end of 30 min. - Light pitting at high speed end of leading edge. At end of 80 min. - Black conductive coating eroded from most of leading edge. At end of 150 min. - 4 holes 1/16 to 1/8" D eroded through coating and 20-30 plies at high speed end.
B					30 min.	110 min.	145 min.	At end of 110 min. - 1/16" D hole through coatings at high speed end, in Spec. A. Spec. B - Small hole through coating at low speed end of leading edge. At end of 145 min. - Spec. B 3/8" D hole through coating and laminate at low speed end of leading edge. 1/16" D hole through 15-20 plies 1" from high speed end.
536 A	Bostik 1007	Gaco N-79 (6 brush coats)	1 yr.	9	15 min.	20 min.	25 min.	At end of 15 min. - Light pitting along high speed end. At end of 20 min. - Spec. A - Small hole through coating at high speed end of leading edge.
B				9	15 min.	25 min.	30 min.	At end of 25 min. - Spec. A - Coating bubbled and ruptured for 1/2" to high speed end. Eroded through 10-15 plies. Spec. B - Coating bubbled at high speed end of leading edge. At end of 30 min. - Spec. B - Eroded through 10-15 plies in 1/2" hole at high speed end. Coating bubbled along 1/2 of leading edge.

TABLE NO. 4 (CONT.)

Specimen No.	Primer	Topcoat	Outdoor Exposed	Thickness Coating (Mils)	Time To Initiate Erosion	Time To Erode Thru Coating	Total Time Of Exposure	Remarks
416 A	Bostik 1007	Goodyear 23-56 (Brush)	3 mos.	10	20 min.	75 min.	90 min.	At end of 20 min. - Abraded along entire leading edge with light pitting at high speed end. At end of 75 min. - Eroded through coating along edge of high speed clip. At end of 90 min. - 1/8" D hole through coat and 10-15 plies at high speed end of leading edge.
420 B	Bostik	Goodyear 23-56 (Spray)	3 mos.	10	20 min.	50 min.	60 min.	At end of 20 min. - Fine pitting along high speed end of leading edge. At end of 50 min. - Coating bubbled and ruptured at high speed end. At end of 60 min. - Eroded through coat and 15-20 plies for 1" of leading edge to high speed end.

TABLE NO. 4 (CONT.)

Specimen No.	Primer	Topcoat	Outdoor Exposed	Thickness Coating (Mils)	Time To Initiate Erosion	Time To Erode Thru Coating	Total Time Of Exposure	Remarks
535 A	Bostik 1007	Gaco N-79 (8 oz/gal N-300-9) (Brush)	6 mos.	9	15 min.	25 min.	80 min.	At end of 15 min. - Fine abrasion and pitting along high speed end. At end of 25 min. - Eroded through coating along edge of high speed clip. At end of 40 min. - Spec. B - Coating bubbled at high speed end. Eroded through 10-15 plies for 1/2" of leading edge at high speed end. At end of 80 min. - Spec. A - Eroded through 8-10 ply along edge of high speed clip. 1/32" D hole through 10-15 plies in center of leading edge.
B					15 min.	25 min.	40 min.	
551 A	Bostik 4764-27	Gaco N-700-9 (8 oz/gal N-300-9) (Brush)	3 mos.	9	15 min.	50 min.	60 min.	At end of 15 min. - Light pitting along high speed end. At end of 50 min. - Eroded through coating at edge of high speed clip. At end of 60 min. - Spec. A - Bubbled along most of leading edge. Eroded through 10-20 plies 1" to high speed end. Spec. B - Bubbled and ruptured at low speed and high speed end of leading edge.
B					15 min.	50 min.	60 min.	

TABLE NO. 4 (CONT.)

Specimen No.	Primer	Topcoat	Outdoor Exposed	Thickness Coating (Mils)	Time To Initiate Erosion	Time To Erode Thru Coating	Total Time Of Exposure	Remarks
554 A	Bostik 4764-27	Goodyear 23-56 (Brush)	3 mos.	10	20 min.	40 min.	55 min.	At end of 20 min. - Fine pitting at high speed end of leading edge. At end of 40 min. - Spec. A - 1/8" D bubble at high speed end of leading edge. At end of 55 min. - Spec. A - 1/4" hole through 15-20 ply at high speed end. At end of 75 min. - Spec. B - Small bubbles at low speed end. Pin hole through coat at edge of low speed clip. At end of 105 min. - Increased bubbling at low speed end. Scattered holes through coating at low speed end of leading edge.
B					20 min.	75 min.	105 min.	

TABLE NO. 5
Rain Erosion of Coatings
500 M.P.H. - 1"/Hr. Rainfall
Gaco Neoprene Coatings
Gates Engineering Co.

Specimen No.	Primer	Topcoat	Curing Schedule	Thickness Coating (Mils)	Time To Initiate Erosion	Time To Erode Thru Coating	Total Time Of Exposure	Remarks
664 A	Gaco N-15	Gaco N-79	Air Dry	9.0	25 Min.	50 Min.	55 Min.	At end of 25 min. - Scattered pitting along high speed end of leading edge. At end of 50 min.-Spec. A- Coating heavily pitted along entire leading edge. Pin hole through coating at high speed end of leading edge. At end of 55 min. -Spec. A- 1/8" D hole through coating and 8-10 plies at high speed end. Two small holes through coating and 3-5 plies in center of leading edge. Spec. B - Coating heavily pitted along entire leading edge. Through coating at edge of high speed clip. At end of 60 min. - Spec.B- Eroded through 10-15 plies at edge of high speed clip.
B				8.5	25 Min.	55 Min.	60 Min.	

TABLE NO. 5 (CONT.)

Specimen No.	Primer	Topcoat	Curing Schedule	Thickness Coating (Mils)	Time To Initiate Erosion	Time To Erode Thru Coating	Total Time Of Exposure	Remarks
665 A	Gaco N-15	Gaco N-79	Air Dry	9.0	30 min.	40 min.	45 min.	At end of 30 min. - Scattered pitting along high speed end of leading edge. At end of 40 min. - Spec. A - Eroded through coating at edge of high speed clip. Pin hole through coating 1" from high speed end. At end of 45 min. - Spec. A - Eroded through 8-10 plies along edge of high speed clip. Four small holes through coating at high speed end of leading edge. Spec. B - Pin hole through coating 1" from high speed end of leading edge. At end of 60 min. - Spec. B - Eroded through 8-10 plies in several small holes at high speed end of leading edge.
B				9.0	30 min.	45 min.	60 min.	

TABLE NO. 5 (CONT.)

Specimen No.	Primer	Topcoat	Curing Schedule	Thickness Coating (Mils)	Time To Initiate Erosion	Time To Erode Thru Coating	Total Time Of Exposure	Remarks
669 A	Gaco N-15	Gaco N-79	Air Dry Bake 20 Hrs. at $200^{\circ}F$	9.0	25 min.	45 min.	50 min.	At end of 25 min. - Light scattered pitting at high speed end of leading edge. At end of 45 min. - Spec. A - Heavy pitting along entire leading edge. 2 pin holes through coating at high speed end of leading edge. Spec. B - Heavy pitting along entire leading edge. Small hole through coating at high speed end of leading edge. At end of 50 min. - Spec. A - Eroded through 10-15 plies in several holes at high speed end of leading edge. Spec. B - Heavy pitting along entire leading edge. Two pin holes through coating at high speed end of leading edge. At end of 55 min. - Spec. B - Eroded through 8-10 plies along edge of high speed clip and 1/8" D hcle at high speed end of leading edge.
B				9.0	25 min.	50 min.	55 min.	

TABLE NO. 5 (CONT.)

Specimen No.	Primer	Topcoat	Curing Schedule	Thickness Coating (Mils)	Time To Initiate Erosion	Time To Erode Thru Coating	Total Time Of Exposure	Remarks
670 A	Gaco N-15	Gaco N-79	Air Dry Bake 20 Hrs. at 200°F	9.0	25 min.	45 min.	50 min.	At end of 25 min. - Light scattered pitting along high speed end of leading edge. At end of 45 min. - Heavy pitting along entire leading edge. Small hole through coating at high speed end of leading edge. At end of 50 min. - Eroded through 8-10 plies in several small holes at high speed end of leading edge.
B				9.0	25 min.	45 min.	50 min.	

IB. Anti-Static Coatings

In order to carry off static charges on neoprene covered aircraft surfaces, anti-static coatings as outlined in MIL-C-7439A, class II, are necessary. To meet this need, both Gates Engineering Company and Goodyear Tire and Rubber Company developed conductive coatings.

Gates N-51 and Goodyear R14L-23-252 were evaluated for rain erosion resistance as outlined in specification MIL-C-7439A (reference 15) as follows.

Ten test specimens of glass reinforced laminates with 2 mils Gaco N-15 primer, approximately 5-6 mils Gaco N-79 and 2 mils of Gaco N-51 anti-static material were brush coated.

Specimen No.	Tests
671 A & B 672 A & B	Rain Erosion Tests - 500 mph & 1"/hr.
676 A & B 680 A & B	Rain Erosion Tests - 500 mph & 1"/hr. after exposure - 200°F for 20 hrs.
673 A & B	Outdoor Exposure - 3 months

Six specimens were primed with Bostik 1007 and coated with Goodyear 23-56 neoprene. A 2 mil film of Goodyear's anti-static coating R14L-23-252 was brushed on the specimens to give a total coating thickness of approximately 10 mils.

The specimens were numbered and prepared for the standard rain erosion test as follows:

Specimen No.	Tests
808 A & B	Rain Erosion Tests - 500 mph & 1"/hr.
809 A & B	Rain Erosion Tests - 500 mph & 1"/hr. after exposure - 200°F for 20 hrs.
810 A & B	Outdoor Exposure - 3 months

Erosion tests at 500 mph and 1"/hr. rainfall were carried out on specimens #671, 679, and 808 after air drying for 150 hours at room temperature. Specimens #678, 680, and 809 were air dried at room temperature for 150 hours and then exposed to 200°F for 20 hours and evaluated for rain erosion resistance under standard conditions as noted above. The specimens of the Gates air dried coatings after testing are shown in Figure No. 4.

Specimens #673 and 810 were placed on outdoor exposure for three months at Buffalo, New York.

The results on the Gaco N-51 anti-static coating are shown in bar graph on page 103. All the results on Gaco and Goodyear anti-static coatings are outlined in Table #6 on pages 24 through 29.

Based upon these tests, Gaco N-51 and Goodyear R14L-23-252 anti-static coatings satisfactorily meet the rain erosion requirement of specification MIL-C-7439A (reference 15).

The electrical transmission tests on Goodyear R14L-23-252 anti-static coating have been checked by Wright Air Development Center and have been found satisfactory. Tests on electrical transmission of Gaco N-51 are in the process of being checked.

TABLE NO. 6
Rain Erosion of Coatings
500 M.P.H. - 1"/Hr. Rainfall
Tests on Gaco N-51 Conductive Top Coating

Specimen No.	Primer	Tie Coat	Topcoat	Curing Schedule	Thickness Coating (Mils)	Time To Initiate Erosion	Time To Erode Thru Coating	Total Time Of Exposure	Remarks
671 A	Gaco N-15 (Brush 2 Coats)	Gaco N-79 (Brush 6 Coats)	Gaco N-51 (Brush 1 Coat)	Air Dry	9	10 min.	40 min.	45 min.	At end of 10 min. - Scattered pitting through black topcoat along high speed end. At end of 40 min. - Black topcoat eroded from entire leading edge. Two pin holes through neoprene coatings at high speed end of leading edge. At end of 45 min. - Eroded through 15-20 plies for 1/4" of leading edge to high speed end.
671 B	Gaco N-15 (Brush 2 Coats)	Gaco N-79 (Brush 6 Coats)	Gaco N-51 (Brush 1 Coat)	Air Dry	9	10 min.	45 min.	50 min.	At end of 10 min. - Scattered pitting through black topcoat along high speed end of leading edge. At end of 45 min. - Black topcoat eroded from entire leading edge. Small hole eroded through coatings at high speed end of leading edge. At end of 50 min. - Coating bubbled for 1" of leading edge to high speed end. 1/4" D hole through several plies at high speed end of leading edge.

TABLE NO. 6 (CONT.)

Specimen No.	Primer	Tie Coat	Topcoat	Curing Schedule	Thickness Coating (Mils)	Time To Initiate Erosion	Time To Erode Thru Coating	Total Time Of Exposure	Remarks
672 A	Gaco N-15 (Brush 2 Coats)	Gaco N-79 (Brush 6 Coats)	Gaco N-51 (Brush 1 Coat)	Air Dry	8.5	20 min.	40 min.	45 min.	At end of 20 min. - Spec. A - Scattered pitting through black topcoat. At end of 10 min. - Spec. B - Scattered pitting through black topcoat at high speed end. At end of 40 min. - Black topcoat eroded from most of leading edge. Small hole through coatings at high speed end of leading edge. At end of 45 min. - Eroded through 10-15 plies along edge of high speed clip.
B					8.5	10 min.	40 min.	45 min.	
676 A	Gaco N-15 (Brush 2 coats)	Gaco N-79 (Brush 6 Coats)	Gaco N-51 (Brush 1 Coat)	Air Dry Bake 20 hrs. at 200° F	8.5	20 min.	40 min.	45 min.	At end of 20 min. - Scattered pitting through black topcoat along high speed end of leading edge. At end of 40 min. - Black topcoat eroded from leading edge. Eroded through coatings in small hole at high speed end. At end of 45 min. - Spec. A - Eroded through 8-10 plies for 1/2" of leading edge. Spec. B - 1/8" D hole through 5-7 plies at high speed end of leading edge.
B					9	20 min.	40 min.	45 min.	

TABLE NO. 6 (CONT.)

Specimen No.	Primer	Tie Coat	Topcoat	Curing Schedule	Thickness Coating (Mils)	Time To Initiate Erosion	Time To Erode Thru Coating	Total Time Of Exposure	Remarks
680 A	Gaco N-15 (Brush 2 Coats)	Gaco N-79 (Brush 6 Coats)	Gaco N-51 (Brush 1 Coat)	Air Dry Bake 20 hrs. at 200° F	9	20 min.	45 min.	50 min.	At end of 20 min. - Scattered pitting through black topcoat at high speed end of leading edge. At end of 45 min. - Black topcoat eroded from most of leading edge. Small hole through coatings at high speed end of leading edge. At end of 50 min. - Spec. A - 1/8" D hole through 8-10 plies at high speed end of leading edge. Spec. B - Eroded through 10-12 plies for 1" of leading edge to high speed end.
B					9	20 min.	45 min.	50 min.	
673 A	Gaco N-15 (Brush 2 coats)	Gaco N-79 (Brush 6 Coats)	Gaco N-51 (Brush 1 Coat)	Exposed outdoors 3 mos.	9	10 min.	35 min.	45 min.	Spec. A & B - Scattered pin holes through the N-51 anti-static coat were noted after 10 min. At end of 35 min. - Most of the N-51 coating was eroded off the leading edge and a small pin hole eroded through the remaining coat at the high speed end. At end of 45 min. - Coating eroded off at the high speed end and several layers of fiberglas eroded away.
B					9	10 min.	35 min.	45 min.	

TABLE NO. 6 (CONT.)

Tests on Goodyear R14L-23-252 Anti-Static Coating

Specimen No.	Primer	Tie Coat	Topcoat	Thickness Coating (Mils)	Time To Initiate Erosion	Time To Erode Thru Coating	Total Time Of Exposure	Remarks
808 A	Bostik 1007	Goodyear 23-56	R14L-23-252	12	40 min.	109 min.	204 min.	Spec. A - Several small holes were visible in the anti-static topcoat in 40 minutes. By 75 minutes, this coating was completely eroded off the base coat on the high speed half of the leading edge. A small hole eroded through the base coat in 109 minutes and was enlarged to 1/2" D in 204 minutes.
B					40 min.	100 min.	141 min.	Spec. B - The anti-static topcoat eroded off in the same time as it did on Spec. A; however, several small bubbles appeared on the base coat in 90 minutes near the high speed end of the leading edge. These ruptured in 100 minutes and a 1" D section of the coating delaminated.

TABLE NO. 6 (CONT.)

Specimen No.	Primer	Tie Coat	Topcoat	Thickness Coating (Mils)	Time To Initiate Erosion	Time To Erode Thru Coating	Total Time Of Exposure	Remarks
809 A	Bostik 1007	Goodyear 23-56	R14L-23-252	12	35 min.	105 min.	170 min.	Spec. A - Scattered holes were visible in the anti-static topcoat after 35 minutes. This topcoat was eroded off the high speed half of the leading edge in 65 minutes. A small hole eroded through the base coat in 105 minutes and after 170 minutes the hole eroded through the 1/8" laminate. Several more pin holes had eroded through the base coat.
B					35 min.	95 min.	140 min.	Spec. B - The anti-static topcoat eroded off in the same time as Specimen A. After 95 minutes a small hole eroded through the base coat at the high speed end of the leading edge. It enlarged to 1/4" D and eroded through 8-10 plies of the laminate in 140 minutes.

TABLE NO. 6 (CONTD.)

Specimen No.	Primer	Tie Coat	Topcoat	Thickness Coating (Mils)	Time To Initiate Erosion	Time To Erode Thru Coating	Total Time Of Exposure	Remarks
810 A	Bostik 1007	Goodyear 23-56	R14L-23-252	12	15 min.	65 min.	70 min.	Spec. A - Scattered holes were eroded through the topcoat after 15 minutes. A small bubble formed at the center of the leading edge in 20 minutes. After 50 minutes of the test the high speed half of the leading edge was bubbled. A hole eroded through the coating in 65 minutes and by 70 minutes there were holes at the center and high speed end of the leading edge.
B					15 min.	130 min.	135 min.	Spec. B - After 15 minutes scattered holes eroded through the topcoat. The leading edge was pitted lightly in 50 minutes. Scattered bubbles appeared at the high speed end in 120 minutes. A hole eroded through the bubbles in 130 minutes and enlarged to 3/8" D in 135 minutes.

IC. Tests on Primers

It has been previously reported that neoprene coatings such as Goodyear 23-56 or Gates N-79 have good rain erosion resistance properties when applied over glass reinforced laminates or aluminum; however, the success of these coatings is dependent to a very large extent on the ability of a primer coat to bond the neoprene to metal or laminate, for the neoprene does not have sufficient adhesion to metal and glass reinforced laminates.

Previously, Gates Primer N-100-1 and Bostik 1007 were evaluated with the solvent type neoprene such as Goodyear 23-56 and Gates N-700-9. Minnesota Mining and Manufacturing Company's primer EC-579 was investigated; however, it had to be used with a tie coat EC-1086 to insure bond of the neoprene latex topcoat EC-1096.

Based upon these previous tests, Bostik 1007 was found to be the most satisfactory. However, B. B. Chemical Company indicated that Bostik primer 1007, used in the neoprene coating systems, might be unavailable in the future due to the withdrawal from the market of one of the compounding ingredients. Several new Bostik primers were offered as substitutes. Other primers were also evaluated and they are listed below.

TABLE NO. 7

Description of Primers

Material	Mfg.	Viscosity	Application	General Type	Remarks
Bostik 4764-27	B.B. Chemical Co. Cambridge, Mass.	Medium	Brush or Spray	Solvent Rubber	May be reduced with MEK to spray.
Bostik 4764-76	" " "	"	" "	"	" " " "
Bostik 4764-88	" " "	"	" "	"	" " " "
Bostik 4764-90	" " "	"	" "	"	" " " "
Gaco N-15	Gates Eng. Company	Low	Brush or Spray	Solvent Rubber Resin	Gives a somewhat grainy coating
Thixon G-135	Dayton Chemical Products Laboratories	Medium	Brush or Spray	Solvent Rubber Resin	" " " "

TABLE NO. 7 (Cont.)

Material	Mfg.	Viscosity	Application	General Type	Remarks
Goodyear 450C	Goodyear Tire & Rubber Co.	Medium	Brush or Spray	Solvent Rubber	Gives smooth coating.
3M-EC-579	Minnesota Mining & Mfg. Co.	Very Low	Brush or Spray	Solvent Resin	Gives a smooth coating.
Pliobond	Goodyear Tire & Rubber Co.	Medium	Brush	Solvent Rubber Resin	May be reduced with MEK to spray
Hysol 6109	Houghton Laboratories Olean, N.Y.	High	Brush	Solvent Epoxide Resin	Has to have Hardner N added before use
Pro Seal 581	Coast Paint & Chemical Co. Los Angeles California	Medium	Brush	Solvent Rubber	Gives smooth coating.

Of all the above primers evaluated, 3M-EC-579 had the best application properties, but upon brush application of Goodyear 23-56 or Gates N-79, the solvent in the neoprene tended to wash off the EC-579 from the glass laminate, by solvent action. This objectionable feature was overcome by allowing the EC-579 to air dry for several days or by spraying the neoprene coating over the EC-579.

Pliobond can be reduced for spray application; but, when sufficient solvent is added to prevent cobwebbing, the solid content is very low necessitating three spray coats.

Hysol 6109 was catalyzed with 6.8 parts of Hardner N added to 100 parts of 6109 before use. The pot life was approximately 6 hours at 85°F. The Bostik samples were similar to Bostik 1007. The Thixon and Gaco N-15 primers gave a grainy film but were satisfactory. For the specimens used in these tests, all the primers were applied by brushing.

Specimens fabricated of Fiberglas 181-114 and Selectron 5003 resin, were sanded with #320 "wet or dry" paper, washed with toluol, and coated as outlined in Table No. 8, below.

TABLE NO. 8
Primer Evaluation
Rain Erosion Tests at
500 M.P.H. - 1"/Hr. Rainfall

Specimen No.	Primer	Dilution	Top Coat
639 A & B	Bostik 4764-76	1:1 with Methyl Ethyl Ketone	Gaco N-79

TABLE NO. 8 (Cont.)

Specimen No.	Primer	Dilution	Top Coat
640 A & B	Bostik 4764-76	1:1 with Methyl Ethyl Ketone	Goodyear 23-56
641 A & B	Bostik 4764-88	1 part Methyl Ethyl Ketone 2 parts Bostik	Gaco N-79
642 A & B	" " "	" " "	Goodyear 23-56
643 A & B	Bostik 4764-90	1:1 with Methyl Ethyl Ketone	Gaco N-79
644 A & B	" " "	" " "	Goodyear 23-56
645 A & B	Pro-Seal 581	As Received	Gaco N-79
646 A & B	" " "	" "	Goodyear 23-56
539 A & B	Bostik 4764-27	No Dilution	Gaco N-79
540 A & B	" " "	" "	Gaco N-79
541 A & B	" " "	" "	Gaco N-79
542 A & B	" " "	" "	Goodyear 23-56
543 A & B	" " "	" "	Goodyear 23-56
544 A & B	" " "	" "	Goodyear 23-56
551 A & B	" " "	" "	Gaco N-79
556 A & B	" " "	" "	Goodyear 23-56
591 A & B	N-15	" "	Gaco N-79
599 A & B	N-15	" "	Goodyear 23-56
652 A & B	N-15	" "	" " "
653 A & B	N-15	" "	" " "

TABLE NO. 8 (Cont.)

Specimen No.	Primer	Dilution	Top Coat
593 A & B	EC-579	Used as received	Gaco N-79
594 A & B	EC-579	" " "	Goodyear 23-56
595 A & B	Pliobond	" " "	Gaco N-79
596 A & B	Pliobond	" " "	Goodyear 23-56
614 A & B	" "	" " "	" " "
615 A & B	" "	" " "	" " "
597 A & B	Hysol 6109	" " "	Gaco N-79
598 A & B	" "	" " "	Goodyear 23-56
611 A & B	Thixon G-135	1 part Amyl Acetate	Goodyear 23-56
612 A & B	" "	1 part Toluol 8 parts Thixon	Gaco N-79
618 A & B	Thixon G-135	" " "	Goodyear 23-56
619 A & B	" "		Goodyear 23-56
630 A & B	" "	" " "	Goodyear 23-56
631 A & B	" "		Gaco N-79
654 A & B	Thixon G-135	" " "	Goodyear 23-56
655 A & B	" "	" " "	Gaco N-79
616 A & B	Goodyear 450C	Unknown	Goodyear 23-56
617 A & B	" " "	"	Goodyear 23-56

The specimens were allowed to air dry for five days before testing. After this period, the specimens were evaluated for rain erosion resistance at 500 mph and 1"/hour rainfall. Some were exposed at 200°F for 20 hours, others at 400°F for 10 minutes and others outdoors for three months to one year, then tested for rain erosion resistance at 500 mph and 1"/hr. rainfall.

Results of Tests on Primers

The results obtained with the neoprene coatings using the above primers are shown in Table No.9 . Casual inspection of the time to erode through the neoprene coatings indicates no great difference in the relative rain erosion resistance of the coatings with the various primers under evaluation. However, there is a great deal of difference in the adhesion of the neoprene coatings to the primers after test.

Both Goodyear 23-56 and Gaco N-79 had excellent adhesion to Gaco N-15 primer, both before and after test.

Goodyear 23-56 had slightly better adhesion to EC-579 than Gaco N-79 but they were both satisfactory before and after testing. The only objectionable feature of EC-579 is its tendency to be washed off by the solvent in the neoprene coating during brush application of the first coat.

Gaco N-79 had definitely poorer adhesion to the Pliobond than did Goodyear 23-56. However, the bond of both neoprene coatings to Pliobond was unsatisfactory, both before and after test. During test, the neoprene coatings had such poor adhesion that they would creep and lost practically all adhesion. This same characteristic was also observed with the Hysol 6109.

Based upon these tests Gaco N-15 primer warrants extensive testing. 3M-EC-579 would merit further investigation if the dried film was not susceptible to attack by the solvent in the Goodyear 23-56 and Gaco N-79 top coating.

Goodyear 23-56 and Gates N-79 had satisfactory rain erosion resistance and excellent adhesion to Thixon G-135, both before and after testing.

Although the Bostik primers behave very much alike, on the basis of these few tests it would seem that Bostik 4764-76 gives the best adhesion, followed by Bostik 4764-88, -27, -90. All four of the Bostik primers tested meet preliminary requirements of MIL-C-7439A. Preliminary erosion tests were made on the primer for neoprene cement submitted by Coast Paint and Chemical Company of Los Angeles, California, Pro-Seal 581 primer.

The results of the rain erosion tests at 500 mph and 1"/hr. rainfall, using Goodyear 23-56 and Gaco N-79 neoprene coatings over the Pro-Seal primer are shown in Table No. 9 and in the bar graph on page 108.

Specimens with Goodyear and Gaco coating over the Pro-Seal 581 primer, #645 and 646, are shown in Photograph #1. The Pro-Seal 581 primer had satisfactory adhesion to the laminate specimen under the Goodyear 23-56 coating but lifted from the specimen when used under the Gaco N-79 neoprene with subsequent bubbling.

Outdoor Durability Tests on Primers

The outdoor durability tests using various primers with Gaco N-79 and Goodyear 23-56 top coatings were completed and erosion tests carried out. The specimens were exposed outdoors in Buffalo, New York, on a rack at 45° facing south for the periods noted.

Specimen No.	Primer	Neoprene Top Coat	Months of Outdoor Exposure
654 A & B	Thixon G-135	Goodyear 23-56	3
655 A & B	Thixon G-135	Gaco N-79	3
652 A & B	Gaco N-15 (P-225-D-11)	Goodyear 23-56	3
653 A & B	Gaco N-15 (P-225-D-11)	Gaco N-79	3
556 A & B	Bostik 4764-27	Goodyear 23-56	12
553 A & B	Bostik 4764-27	Gaco N-79	12

The specimens were tested at 500 mph and 1"/hr. rainfall. The results are outlined in Table No. 10 and bar graph on page 109.

Based upon the examination of these specimens and results of these and previous erosion tests, the above primers when used with Gates N-79 and Goodyear 23-56 top coatings meet the three month outdoor exposure test outlined in MIL-C-7439.

Bostik 4764-27 coated specimens #553 with Gaco N-79 and #556 with Goodyear 23-56 top coats, after one year's exposure, are shown in Figure No. 2. Microscopic examination of both top coats indicates alligatoring of the neoprene films. Gaco N-79 showed slightly greater amount compared to Goodyear 23-56. This effect is not visible to the unaided eye.

Heat Tests on Primers and Coatings

Further evaluation tests on primers for bonding neoprene to glass reinforced laminates were carried out. Test specimens, as noted, were given two brush coats of reduced Thixon G-135 primer. The Thixon primer being slightly high in viscosity was reduced 25% with a mixture of equal parts by volume of amyl acetate and toluol. Four standard test specimens were given two brush coats of Gaco primer N-15. The viscosity of this primer was satisfactory and needed no thinning for brush application. After allowing the specimens to air dry for 30 minutes at room temperature, they were numbered and brush coated with Goodyear 23-56 and Gaco N-79 to give a ten mil coating. The samples prepared were as follows:

Specimen No.	Primer	Neoprene Coating
630 A & B	Thixon G-135	Goodyear 23-56
631 A & B	Thixon G-135	Gaco N-79
632 A & B	Gaco N-15	Goodyear 23-56
633 A & B	Gaco N-15	Gaco N-79

These specimens were allowed to air dry for 100 hours at room temperature and then put in an oven at 175°F for 4 hours to remove the residual solvent. The eight specimens were then put into an oven at 400°F for 10 minutes.

Specimens #630 and 631 with Thixon G-135, Goodyear 23-56 and Gates N-79, blistered badly when exposed to the 400°F temperature for 10 minutes. The blistered area covered most of the specimen.

Specimens #632 with Gates primer N-15 and Goodyear 23-56 top coating blistered slightly in several spots along the leading edge but were not as bad as specimens #630 and 631. Specimens #633 with Gates primer N-15 and N-79 top coat did not blister and appeared satisfactory. All specimens, however, were tested for erosion resistance at 500 mph and 1"/hr. rainfall. Specimens #630, 631 and 632 all failed in periods ranging from 3 to 10 minutes due to rupturing of the blisters and consequent erosion of the glass laminate beneath. Specimens #633 lasted for 35 to 40 minutes indicating a slight loss in erosion resistance after exposure to 400°F for ten minutes. The results are tabulated in Table No. 11 on page 51.

Tests on Goodyear Primers and Coatings.

Additional tests on primers were carried out on specimens prepared by the Research Laboratory of Goodyear Tire and Rubber Company. Samples of glass-reinforced test specimens were coated with three primers as outlined below. Two coats of each primer were brushed on and the top coat of Goodyear 23-56 sprayed on.

Evaluation Tests on Primers with Goodyear 23-56

Specimen No.	Primer	Top Coat
614 A & B	Pliobond	Goodyear 23-56
615 A & B	" "	" " "
616 A & B	Goodyear M-450-C	Goodyear 23-56
617 A & B	" "	" " "
618 A & B	Thixon G-135	Goodyear 23-56
619 A & B	" "	" " "

The results obtained with the Goodyear neoprene 23-56 using the above primers are shown in Table No. 12 on pages 52 through 54, and in bar graph on page 118. Analysis of the date shows that Pliobond and Thixon G-135 give satisfactory adhesion to Goodyear 23-56 during the erosion test. Goodyear primer M-450-C allowed the Goodyear 23-56 to bubble during erosion test indicating unsatisfactory adhesion properties.

The bond of the Pliobond and Thixon G-135 to the neoprene coating 23-56 was evaluated, subjectively, by cutting two parallel lines 1/4" apart, through the coating and peeling back the 1/4" tab of neoprene coating.

The adhesion of the Thixon G-135 was excellent both before and after erosion testing. As previously noted, the adhesion of the neoprene to the Pliobond both before and after testing was considerably inferior to that obtained with Bostik 1007.

Summary of Results on Primers

Based upon such properties as general application characteristics, adhesion before and after erosion testing, resistance to 400°F, conformance to tests outlined in specification MIL-C-7439A (except electrical tests) the following comments can be made on the primers tested.

Bostik 4764-27	-	Satisfactory for normal condition. Meets MIL-7439. Heat resistance at 400°F unsatisfactory.
Bostik 4764-76	-	" " " " " " " " " " "
Bostik 4764-88	-	" " " " " " " " " " "
Bostik 4764-90	-	" " " " " " " " " " "
Thixon G-135	-	" " " " " " " " " " "
Gates N-15	-	Satisfactory for all conditions up to 375°F- Meets specifications MIL-7439.
EC-579	-	Solvent resistance unsatisfactory
Pro-Seal 581	-	Satisfactory with Pro-Seal top coat and Goodyear 23-56 - unsatisfactory with Gates N-79
Goodyear 450-C	-	Unsatisfactory - poor adhesion with Goodyear 23-56.
Hysol 6409	-	Unsatisfactory - poor adhesion
Pliobond	-	Unsatisfactory - poor adhesion

TABLE NO. 9
Rain Erosion of Coatings
500 M.P.H. - 1"/Hr. Rainfall
Tests on Primers For Neoprene Coatings

Specimen No.	Primer	Application	Topcoat	Thickness Coating (Mils)	Time To Initiate Erosion	Time To Erode Thru Coating	Total Time Of Exposure	Remarks
591 A	Gaco 225-11-D Radome Coating Primer	Brush (2 coats)	Gaco N-79 (8 oz/ N-300-9) per gal. N-700-9	10	30 min.	60 min.	70 min.	At end of 30 min. - Scattered pitting at high speed end of leading edge. At end of 60 min. - Spec. A - Pin hole through coating at high speed end. Spec. B - Coating bubbled 1/2" from high speed end. At end of 70 min. - Spec. A- Bubbled in center and at low speed end of leading edge. Small hole through several ply at high speed end. Spec. B - 1/4" hole through 10-12 plies at high speed end.
B					30 min.	60 min.	70 min.	
599 A	Gaco 225-11-D Radome Coating Primer	Brush (2 coats)	Goodyear 23-56	11	40 min.	90 min.	115 min.	At end of 40 min. - Light pitting at high speed end of leading edge. At end of 90 min. - Spec. A - Three small bubbles at high speed end. Pin hole through one bubble. At end of 105 min. - Spec. B - Eroded through coating at edge of high speed clip. At end of 115 min. - Spec. A - Through coating and 10-15 plies in 1/6" hole at high speed end. Spec. B - Eroded through several plies along edge of high speed clip.
B					40 min.	105 min.	115 min.	

TABLE NO. 9 (CONT.)

Specimen No.	Primer	Application	Topcoat	Thickness Coating (Mils)	Time To Initiate Erosion	Time To Erode Thru Coating	Total Time Of Exposure	Remarks
593 A	3M-EC-579	Brush (2 coats)	Gaco N-700-9 (8 oz/gal N-300-9)	9	30 min.	40 min.	40 min.	At end of 30 min.-Spec. A - Scattered pitting along high speed end. Spec. B - 1/8" bubble at high speed end. At end of 40 min. - Spec. A - Coating bubbled and ruptured in 1/4" hole at high speed end. Spec. B - Eroded through coat and 10-15 plies in 1/8" hole 1/2" from high speed end.
B					30 min.	30 min.	40 min.	
594 A	3M-EC-579	Brush (2 coats)	Goodyear 23-56	9	35 min.	40 min.	45 min.	At end of 35 min. - Scattered pitting at high speed end of leading edge. At end of 40 min. - Spec. A- Coating bubbled along most of leading edge. Spec. B - Coating bubbled at high speed end of leading edge. At end of 45 min. - Spec. A - 1/2" D hole eroded through 3-5 plies at high speed end. Spec. B - 1/2" D bubble at high speed end of leading edge.
B					35 min.	40 min.	45 min.	

TABLE NO. 9 (CONT.)

Specimen No.	Primer	Application	Topcoat	Thickness Coating (Mils)	Time To Initiate Erosion	Time To Erode Thru Coating	Total Time Of Exposure	Remarks
595 A	Pliobond Goodyear Tire & Rubber Co.	Brush (2 coats)	Gaco N-700-9	12	35 min.	140 min.	150 min.	At end of 35 min. - Scattered pitting at high speed end of leading edge. At end of 125 min. - Spec. B- Small bubble at high speed end of leading edge. At end of 140 min. - Coating bubbled at high speed end. At end of 150 min. - Coating bubbled and ruptured for 1/2" of leading edge at high speed end.
B					35 min.	125 min.	150 min.	
596 A	Pliobond	Brush (2 coats)	Goodyear 23-56	11	40 min.	75 min.	85 min.	At end of 40 min. - Fine pitting at high speed end of leading edge. At end of 75 min. - Spec. A- Pin hole through small bubble at high speed end. Spec. B - Small bubble $1\frac{1}{4}$" from high speed end. At end of 85 min. - Eroded through coat and 10-15 plies in $\frac{1}{4}$" D hole at high speed end.
B					40 min.	75 min.	85 min.	

TABLE NO. 9 (CONT.)

Specimen No.	Primer	Application	Topcoat	Thickness Coating (Mils)	Time To Initiate Erosion	Time To Erode Thru Coating	Total Time Of Exposure	Remarks
597 A	Hysol 6109	Brush (1 coat)	Gaco N-700-9	12	35 min.	55 min.	55 min.	At end of 35 min. - Scattered pitting at high speed end of leading edge. At end of 55 min. - Spec. A- Coating bubbled and stripped from 1/2 of specimen. Spec. B - Coating bubbled and ruptured in 1/4" D hole at high speed end of leading edge.
B	Houghton Laboratories				35 min.	55 min.	55 min.	
598 A	Hysol 6109	Brush (1 coat)	Goodyear 23-56	10	40 min.	70 min.	110 min.	At end of 40 min. - Light, scattered pitting along leading edge. At end of 60 min. - Spec. B- 1/8" D hole eroded through coat at high speed end of leading edge. At end of 70 min. - Spec. A- Eroded through coating along edge of high speed clip. Spec. B - 1/8" D hole eroded through 20-25 plies at high speed end. At end of 110 min. - Spec. A - Eroded through 20-25 plies along edge of high speed clip
B	Houghton Laboratories				40 min.	60 min.	70 min.	

TABLE NO. 9 (CONT.)

Specimen No.	Primer	Application	Topcoat	Thickness Coating (Mils)	Time To Initiate Erosion	Time To Erode Thru Coating	Total Time Of Exposure	Remarks
639 A	Bostik 4764-76	Brush (2 coats)	Gaco N-79	10	45 min.	65 min.	100 min.	At end of 45 min. - Coating abraded and pitted slightly along entire leading edge. At end of 65 min. - Spec. A - 1/16" cut at edge of high speed clip. At end of 70 min. - Spec. B- 1/6" cut at edge of high speed clip. At end of 100 min. -Spec. A- 5/16" D hole through coating and 15-20 plies at high speed end. Several pin holes through coating along high speed end of leading edge. At end of 115 min. - Spec. B 3/8" D hole through coating and 15-30 plies at high speed end. Several pin holes through coating along high speed end of leading edge.
B				10	45 min.	70 min.	115 min.	

TABLE NO. 9 (CONT.)

Specimen No.	Primer	Application	Topcoat	Thickness Coating (Mils)	Time To Initiate Erosion	Time To Erode Thru Coating	Total Time of Exposure	Remarks
640 A	Bostik 4764-76	Brush (2 coats)	Goodyear 23-56	10	90 min.	115 min.	130 min.	At end of 80 min. - Spec. B - Scattered pitting in coating for 1½" of leading edge to high speed end. At end of 90 min. - Spec. A - Scattered pitting in coating at high speed end. At end of 115 min.-Spec. A - 1/16" cut along high speed clip. Several small bubbles at high speed end. Spec. B- Pin hole through coating at high speed end of leading edge. At end of 130 min.-Spec. A- 3/8" D hole eroded through coating and 8-10 plies at high speed end. At end of 165 min.-Spec. B- 3/8" D hole eroded through coating and 20-30 plies at high speed end of leading edge.
B					80 min.	115 min.	165 min.	

TABLE NO. 9 (CONT.)

Specimen No.	Primer	Application	Topcoat	Thickness Coating (Mils)	Time To Initiate Erosion	Time To Erode Thru Coating	Total Time Of Exposure	Remarks
641 A	Bostik 4764-88	Brush (2 coats)	Gaco N-79	10	45 min.	65 min.	100 min.	At end of 45 min. - Coating abraded and pitted slightly along entire leading edge. At end of 55 min.-Spec. B - Pin hole through coating next to high speed clip. At end of 65 min.-Spec. A- Small cut in coating along high speed clip. At end of 80 min.-Spec. B- 5/16" D hole through coating and 5-10 plies at high speed end of leading edge. Coating bubbled for 1" of leading edge to high speed end. At end of 100 min. -Spec.A- Eroded through coating and 5-10 plies for 1" of leading edge to high speed end. Eroded through laminate at edge of high speed clip.
B				10	55 min.	55 min.	80 min.	

TABLE NO. 9 (CONT.)

Specimen No.	Primer	Application	Topcoat	Thickness Coating (Mils)	Time To Initiate Erosion	Time To Erode Thru Coating	Total Time Of Exposure	Remarks
642 A	Bostik 4764-88	Brush (2 Coats)	Goodyear 23-56	10	80 min.	110 min.	150 min.	At end of 80 min. - Scattered pitting along leading edge. At end of 90 min.-Spec. B-Pin hole through coating at high speed end. At end of 110 min.-Spec.A-Small cut in coating along edge of high speed clip. At end of 140 min.-Spec.B-Coating bubbled and ruptured for 1" of leading edge to high speed end. Eroded completely through laminate at high speed end. At end of 150 min.-Spec. A-Coating bubbled and ruptured for 1" of leading edge to high speed end. Eroded completely through laminate at high speed end.
B					80 min.	90 min.	140 min.	

TABLE NO. 9 (CONT.)

Specimen No.	Primer	Application	Topcoat	Thickness Coating (Mils)	Time To Initiate Erosion	Time To Erode Thru Coating	Total Time Of Exposure	Remarks
643 A	Bostik 4764-90	Brush (2 coats)	Gaco N-79	10	30 min.	60 min.	100 min.	At end of 30 min. - Coating abraded along entire leading edge. At end of 60 min. - Small hole in coating at high speed end. At end of 80 min.-Spec. B-Coating bubbled for 3/4" along leading edge to high speed end. 1/4" D hole through coating and 5-10 plies at high speed end. At end of 100 min.-Spec.A-Coating bubbled and ruptured for 1" of leading edge to high speed end. Eroded through 15-20 plies along edge of high speed clip.
B					30 min.	60 min.	80 min.	
644 A	Bostik 4764-90	Brush (2 coats)	Goodyear 23-56	10	80 min.	80 min.	120 min.	At end of 80 min. - Coating abraded along entire leading edge. At end of 100 min.-Spec. B-Small cut in coating at high speed end. 1/16" bubbled 1/2" from high speed end. At end of 120 min.-Spec. A-5/16" hole through coating and 10-30 plies at high speed end of leading edge. Spec. B-1/2" D hole through coating and 15-20 plies at high speed end of leading edge.
B					80 min.	100 min.	120 min.	

TABLE NO. 9 (CONT.)

Specimen No.	Primer	Application	Topcoat	Thickness Coating (Mils)	Time To Initiate Erosion	Time To Erode Thru Coating	Total Time Of Exposure	Remarks
645 A	Pro-Seal 581	Brush (2 coats)	Gaco N-79	10	30 min.	35 min.	37 min.	At end of 30 min. - Leading edge abraded. At end of 35 min.-Spec. A-Pin hole in coating 1" from high speed end. At end of 37 min.-Spec. A-1/2" D hole through coating 1" from high speed end. Numerous small pin holes in lifted area. At end of 67 min.-Spec. B-Small bubbles in coating for 1/3 of leading edge to high speed end. 1/8" cut along high speed clip. At end of 72 min.-Spec. B-5/16" hole in coating at high speed end. Several small pin holes in lifted area.
B					30 min.	67 min.	72 min.	
646 A	Pro-Seal 581	Brush (2 coats)	Goodyear 23-56	10	25 min.	45 min.	60 min.	At end of 25 min.-Spec. A-Small bubble in center of leading edge. At end of 45 min.-Spec. A-5/16" hole in coating at center of leading edge. At end of 60 min.-Spec. A-5/8" hole in coating at center of leading edge. At end of 80 min.-Spec. B-Leading edge abraded slightly. At end of 105 min.-Spec. B-Pin hole in coating at high speed end. At end of 125 min.-Spec. B-5/16" hole eroded through coating and 15-20 plies at high speed end.
B					80 min.	105 min.	125 min.	

TABLE NO. 10
Rain Erosion of Coatings
500 M.P.H. - 1"/Hr. Rainfall
Exposure Tests on Primers

Specimen No.	Primer	Topcoat	Outdoor Exposure	Thickness Coating (Mils)	Time To Initiate Erosion	Time To Erode Thru Coating	Total Time Of Exposure	Remarks
654 A	Thixon G135	Goodyear 23-56 (10 brush coats)	3 mos.	10	30 min.	60 min.	65 min.	At end of 30 min. - Light pitting at high speed end. At end of 45 min.-Spec. B - Pin hole through coating 1/2" from high speed end. At end of 60 min.-Spec. A- 1/16" D hole through coating at high speed end. At end of 65 min.-Spec. A- Coating bubbled for 1/2 of leading edge to high speed end. 3/8" D hole eroded through 10-15 plies at high speed end. Spec. B - Eroded through coating and 15-20 plies in 1/4" hole at high speed end and 1/8" D hole 1/2" from high speed end.
B					30 min.	45 min.	65 min.	
655 A	Thixon G135	Gaco N-79 (7 brush coats)	3 mos.	9	20 min.	30 min.	60 min.	At end of 20 min.-Scattered pitting along leading edge. At end of 30 min.-Spec. A - Pin hole through coating in center of leading edge. At end of 40 min.-Spec. B - 1/8" D hole through coating at high speed end of leading edge. At end of 55 min.-Spec. B- Coating bubbled and ruptured for 1/2 of leading edge to high speed end. Eroded through 20-25 plies. At end of 60 min.-Spec. A - 3/32" D hole through coat and 8-10 plies scattered along leading edge.
B					20 min.	40 min.	55 min.	

TABLE NO. 10 (CONT.)

Specimen No.	Primer	Topcoat	Outdoor Exposure	Thickness Coating (Mils)	Time To Initiate Erosion	Time To Erode Thru Coating	Total Time Of Exposure	Remarks
652 A	Gaco N-15 (P225-D-11)	Goodyear 23-56 (10 brush coats)	3 mos.	9	30 min.	40 min.	50 min.	At end of 30 min. - Scattered pitting along high speed end of leading edge. At end of 40 min. - Pin hole through coating at high speed end of leading edge. At end of 50 min. - Coating bubbled and ruptured for 3/4" of leading edge to high speed end. Eroded through 10-15 plies.
B					30 min.	40 min.	50 min.	
653 A	Gaco N-15 P225-D-11	Gaco N-79 (7 brush coats)	3 mos.	9	20 min.	35 min.	45 min.	At end of 20 min. - Scattered pitting along leading edge. At end of 30 min. - Two pin holes through coating at high speed end, Spec. B. At end of 35 min. - Spec. A - Few pinholes along high speed end of leading edge. At end of 45 min. - Spec. A - Eroded through coating and 15-20 plies for 3/4" to high speed end. Spec. B - Eroded through coating and 20-25 plies in 1/4" hole at high speed end.
B					20 min.	30 min.	45 min.	

TABLE NO. 10 (CONT.)

Specimen No.	Primer	Topcoat	Outdoor Exposure	Thickness Coating (Mils)	Time To Initiate Erosion	Time To Erode Thru Coating	Total Time Of Exposure	Remarks
553 A	Bostik 4764-27	Gaco N-79 (5 brush coats)	1 year	8	15 min.	25 min.	35 min.	At end of 15 min. - Light pitting at high speed end.
B					15 min.	25 min.	40 min.	At end of 25 min. - Spec. A- Pin hole through coating at high speed end of leading edge. Spec. B - Small bubbles and pin holes along leading edge. At end of 35 min. - Spec. A- Heavy pitting along most of leading edge. Scattered holes through coating along high speed end, 1/2 of leading edge. Eroded through 10-15 plies along high speed clip. At end of 40 min. - Spec. B- Eroded through 10-20 plies in 1/2" hole at high speed end.
556 A	Bostik 4764-27	Goodyear 23-56 (5 brush coats)	1 year	10	15 min.	45 min.	55 min.	At end of 15 min. - Light pitting at high speed end.
B					15 min.	50 min.	60 min.	At end of 45 min. - Two pin holes through coating at high speed end. Coating bubbled at high and low speed ends. At end of 50 min. - Spec. B - 3 pin holes through coating at high speed end. Coating bubbled along most of leading edge. At end of 55 min. - Spec. A - Eroded through coating and 8-10 plies in 1/2" D hole at high speed end. Coating bubbled for 3/4" of leading edge at low speed end.

TABLE NO. 11
Rain Erosion of Coatings
500 M.P.H. - 1"/Hr. Rainfall
Tests on Heat Treated Neoprene Coatings

Specimen No.	Primer	Topcoat	Curing Schedule	Thickness Coating (Mils)	Time To Initiate Erosion	Time To Erode Thru Coating	Total Time Of Exposure	Remarks
630 A	Thixon G-135	Goodyear 23-56	Air Dry 100 Hrs. Bake 4 Hrs. 175°F Bake 10 min. at 400°F	10	-	10 min.	10 min.	Coating badly blistered on both specimens when subjected to 400°F. Blisters ruptured after 10-15 minutes of testing.
B					-	15 min.	15 min.	
631 A	Thixon G-135	Gaco N-79	Air Dry 100 Hrs. Bake 4 Hrs. 175°F Bake 10 min. at 400°F	10	-	8 min.	8 min.	Coating on both specimens blistered almost as badly as #630. Blisters ruptured after 3-8 minutes of testing.
B					-	3 min.	3 min.	
632 A	Gates N-15	Goodyear 23-56	Air Dry 100 Hrs. Bake 4 Hrs. 175°F Bake 10 min. at 400°F	9	-	-	10 min.	Small blisters along leading edge after heat treatment. Blisters ruptured after 3 minutes of testing.
B					-	-	10 min.	
633 A	Gaco P225-11-D	Gaco N-79	Air Dry 100 Hrs. Bake 4 Hrs. 175°F Bake 10 min. at 400°F	9	20 min.	35 min.	40 min.	No blistering from heat treatment. At end of 20 min. - Light pitting along leading edge. At end of 35 min.-Spec. A- Eroded through coating at high speed end of leading edge. At end of 40 min.-Spec. A- Eroded through 8-10 plies of leading edge. Spec. B - Eroded through coating at high speed end.
B					20 min.	40 min.	40 min.	

TABLE NO. 12
Rain Erosion of Coatings
500 M.P.H. - 1"/Hr. Rainfall
Tests on Primers

Specimen No.	Primer	Application	Topcoat	Thickness Coating (Mils)	Time To Initiate Erosion	Time To Erode Thru Coating	Total Time Of Exposure	Remarks
614 A	Pliobond	Brush (2 coats)	Goodyear 23-56 (Spray)	10	30 min.	90 min.	100 min.	At end of 30 min. - Scattered pitting at high speed end of leading edge.
B					30 min.	90 min.	100 min.	At end of 90 min. - Eroded through coating at edge of high speed clip. At end of 100 min. - Eroded through coating and 15-20 plies along edge of high speed clip.
615 A	Pliobond	Brush (2 coats)	Goodyear 23-56 (Spray)	11	30 min.	75 min.	110 min.	At end of 30 min. - Scattered pitting along high speed end of leading edge.
B					30 min.	100 min.	110 min.	At end of 75 min.-Spec. A - Pin hole through coating at extreme high speed end of leading edge. At end of 100 min.-Spec. B- Eroded through coating along edge of high speed clip. At end of 110 min.-Spec. B- Eroded through 10-15 plies along edge of high speed clip. Spec. A- 1/16" D hole eroded through laminate at high speed end of leading edge.

TABLE NO. 12 (CONT.)

Specimen No.	Primer	Application	Topcoat	Thickness Coating (Mils)	Time To Initiate Erosion	Time To Erode Thru Coating	Total Time Of Exposure	Remarks
616 A	Goodyear M-450 C	Brush (2 coats)	Goodyear 23-56 (Spray)	8	30 min.	50 min.	60 min.	At end of 30 min. - Scattered pitting along high speed end of leading edge. At end of 50 min. - Spec. A - 1/2" D bubble in center of leading edge. At end of 60 min. - Spec. A - 3/4" D hole through coat and 8-10 plies in center of leading edge. At end of 110 min.-Spec. B- Small bubble 1" from high speed end. At end of 115 min.-Spec. B- 1/16" D hole through coat and 2-3 plies 1" from high speed end.
B				8	30 min.	110 min.	115 min.	
617 A	Goodyear M-450 C	Brush (2 coats)	Goodyear 23-56 (Spray)	8.5	30 min.	70 min.	70 min.	At end of 30 min. - Light pitting along leading edge at high speed end. At end of 50 min.-Spec. B- Coating bubbled and ruptured for 1" to high speed end. At end of 70 min.-Spec. A- Coating bubbled and ruptured along 1" of leading edge to high speed end.
B				8	30 min.	50 min.	50 min.	

TABLE NO. 12 (CONT.)

Specimen No.	Primer	Application	Topcoat	Thickness Coating (Mils)	Time To Initiate Erosion	Time To Erode Thru Coating	Total Time of Exposure	Remarks
618 A	Dayton Chem.Co. Thixon G-135	Brush (2 coats)	Goodyear 23-56 (Spray)	8	35 min.	80 min.	88 min.	At end of 35 min. - Scattered pitting along high speed end of leading edge. At end of 80 min.-Spec. A - Small bubbles in coating at high speed end of leading edge. Spec. B - Small hole through coat at edge of high speed clip. At end of 88 min.-Spec. A- Coating bubbled and ruptured for 2" along leading edge to high speed end. At end of 100 min.-Spec. B- Eroded through coat and 10-15 plies in 1/8" hole at high speed end.
B				10	35 min.	80 min.	100 min.	
619 A	Dayton Chem.Co. Thixon G-135	Brush (2 coats)	Goodyear 23-56 (Spray)	8	35 min.	80 min.	90 min.	At end of 35 min. Light pitting at high speed end of leading edge. At end of 80 min.-Spec. A- Small hole through coating 1/4" from high speed end. At end of 90 min. - Eroded through coat of Spec. A and 5-8 plies in 3/8" D hole at high speed end. At end of 100 min. - Spec.B- Eroded through coating at edge of high speed clip. At end of 115 min.-Spec. B- Eroded through coating and 15-20 plies along edge of high speed clip.
B				9	35 min.	100 min.	115 min.	

ID. Tests on Deicer Boot Stock

Under Air Force contract, Goodyear Tire & Rubber Company is developing a new rubber stock for deicer boots for aircraft.

Four standard test specimens were received from Goodyear which were identified as follows: Specimens #603 A & B were iceguard cover stock, calendered, cured in sheet form, then cemented onto the standard glass laminate specimen. This iceguard stock ranged from .011" to .012" in thickness. Specimens #604 A & B were prepared in the same manner as Specimens #603, but, in addition, have a spray coat of a compound containing a vinyl and acrylonitrile-butadiene rubber. The spray coat is .007-.008" thick. The purpose of the spray coat was to increase the resistance to solvents which is of some concern in actual service conditions.

These specimens were evaluated at 500 mph and 1"/hour rainfall with the following results. The iceguard sheet stock delaminated due to failure of the adhesive to the glass laminate on all four specimens during the first minute of testing. The sheet material was then rebonded to the test specimen using 3M-562 cement and the test continued.

At the end of ten minutes, the iceguard stock on Specimens #603 A & B was slightly abraded along the entire leading edge. At the end of 15 minutes, the sheet stock flew off specimen #603 A. Tests on Specimen #603 B were conducted and, at the end of 50 minutes, three small holes were abraded through the sheet at the high speed end. The sheet had delaminated slightly on the side; therefore, the tests were discontinued.

The vinyl coating on Specimens #604 A & B showed loss of adhesion to the iceguard sheet, after two minutes at 500 mph. This was noticed due to the formation of small bubbles 1/4" to 1/2" in diameter. Tests on Specimen #604 A were discontinued due to loss of adhesion of the neoprene sheet to the glass laminate. Specimen #604 B was continued for five minutes at which time the test was discontinued for the same reason. However, the .007" to .008" coating of vinyl had abraded through all along the leading edge after five minutes.

In spite of the difficulty with the adhesion of the deicer boot stock, the results indicate that the vinyl coating, 7 to 8 mils thick, erodes through in five minutes, and the 12 mil iceguard sheet stock erodes through in approximately 50 minutes at 500 mph and 1"/hour rainfall.

IE. Tests on Silicone Rubber

Previous evaluation of silicone rubbers for rain erosion resistance has shown that in general, the silicone compounds were soft and lacked the required toughness. Connecticut Hard Rubber Company, however, developed a tough silicone rubber compound R-1985A. Two sets of glass reinforced test specimens #565 and #566 were submitted. A 20 mil sheet of silicone rubber was cemented to the polyester laminate with a silicone adhesive R-1107 and cured at 300°F for four hours. A soft resilient coating of approximately 30 mils in thickness was obtained. The two sets of specimens were tested at 500 mph and 1"/hour rainfall. The surface of the rubber began to abrade in approximately 5 minutes but after 9 to 10 minutes, the silicone coating began to fail in a manner that has never been observed on elastomeric coatings, i.e., long

cracks appeared through the rubber coating. This phenomena was attributed to the fact that under the impact of the rain drops, the soft undercoating of silicone adhesive deformed relatively large amounts causing the silicone rubber to fatigue under the rapid strains imposed. The results obtained are outlined in Table No. 13.

IF. Tests on 3M Coatings

At various times, references have been received to the effect that aircraft manufacturers on the West Coast have found that Minnesota Mining & Manufacturing Company's cements numbered EC-817 and EC-843 have shown excellent rain erosion resistance, in service. However, no actual data have ever been received. Previously, 24ST aluminum test specimens were prepared using zinc chromate primer to specification AN-TT-P-656 and EC-843 as a top coat, as Boeing Aircraft had requested that this material be evaluated. A total film thickness of primer and EC-843 of approximately 3 mils lasted less than two minutes at 500 mph and 1"/hour rainfall, which was considered unsatisfactory. Recently, Minnesota Mining & Manufacturing Company requested rain erosion test specimens of magnesium, 24ST aluminum and polyester glass laminates for coating with modifications of EC-843 and EC-817. Table No. 14 outlines the method of preparation of specimens as well as the primer and top coat used by 3M personnel.

Of the coated glass reinforced laminates tested, only specimens #368 A & B had satisfactory adhesion. Specimens #366 and #367 eroded in a short time but gave indications that the coating, when pigmented with aluminum, tended to be brittle and had inferior adhesion to the glass laminate.

On the metal specimens, this same trend was noticable. The 24ST aluminum specimens #371, having a non-pigmented coating, had the best rain erosion resistance and adhesion. Specimens #370 had better adhesion then specimen #369 but no noticeably greater erosion resistance. On the magnesium, there were no specimens prepared of X-34932-C non-pigmented rubber coating. Specimen #373 had better adhesion when compared to specimen #372 but no noticeably greater rain erosion resistance.

Although none of the three materials, X-34932-C (817); X-231108 + 5% aluminum pigment; and X-33038 + 5% aluminum pigment (843), were outstanding since none of the specimens lasted over 10 minutes when evaluated at 500 mph and 1"/hour rainfall. Based upon their comparative adhesion and rain erosion resistance they can be rated in the following order:

1. X-34932-C (817)
2. X-231108 + 5% aluminum
3. X-33030 + 5% aluminum (843)

The results are outlined in Table No.14 and the specimens after test are shown in Figures 6, 7, and 8.

TABLE NO. 13
Rain Erosion of Coatings
500 M.P.H. - 1"/Hr. Rainfall
Tests on Conn. Hard Rubber Company's Silicone Rubber

Specimen No.	Adhesive	Topcoat	Thickness of Silicone Rubber	Time To Initiate Erosion	Time To Erode Thru Coating	Total Time Of Exposure	Remarks
565 A	R 11007 Cured at 300°F for 4 hours	Silicone Rubber R1985A	20 mil	5 min.	10 min.	15 min.	At end of 5 min. - Fine abrasion along leading edge. Scattered pitting at high speed end. At end of 10 min. - Short cracks (1/8" long) through coating along leading edge. At end of 15 min. - Increased splitting of coating along leading edge.
B			20 mil	5 min.	10 min.	15 min.	
566 A	R 11007 Cured at 300°F for 4 hours	Silicone Rubber R1985A	20 mil	5 min.	10 min.	30 min.	At end of 5 min. - Coating abraded along leading edge. At end of 10 min. - Small cracks through coating at high speed end of leading edge. At end of 30 min. - Coating roughened and broken in many small cracks along leading edge.
B			20 mil	5 min.	10 min.	30 min.	

TABLE NO. 14

Rain Erosion of Coatings

500 M.P.H. - 1"/Hr. Rainfall

Tests on Minnesota Mining & Manufacturing Neoprene Coatings

Specimen No.	Specimen Material	Primer	Topcoat	Time To Initiate Erosion	Time To Erode Thru Coating	Total Time Of Exposure	Remarks
366 A	Fiberglas 116-114	None	3M-X33030 + 5% Aluminum	3 min.	5 min.	6 min.	At end of 3 min. - Spec. A - Light pitting at high speed end of leading edge. Spec. B - Coating flaked off high speed end of leading edge. At end of 5 min. - Spec. A - Eroded through coating at high speed end. At end of 6 min. - Spec. A - Eroded through coating and 3-5 plies for 1/2" to high speed end. Spec. B - Coating flaked off most of leading edge. Eroded through 5-7 plies at high speed and low speed ends.
B	Sel. 5003		(EC 843 Type)	3 min.	3 min.	6 min.	
367 A	Fiberglas 116-114	None	3M-X231108 + 5% Aluminum	2 min.	4 min.	5 min.	At end of 2 min. - Light pitting at high speed end of leading edge. At end of 3 min. - Spec. B - Coating flaked from leading edge for 1½" to high speed end. At end of 4 min. - Spec. A - Eroded through coating at high speed end. At end of 5 min. - Spec. A - Eroded through coating and 2-3 plies for ¼" of leading edge to high speed end. Spec. B - Eroded through 3-4 plies along 1/2 of leading edge to high speed end.
B	Sel. 5003			2 min.	3 min.	5 min.	

TABLE NO. 14 (CONT.)

Specimen No.	Specimen Material	Primer	Topcoat	Time To Initiate Erosion	Time To Erode Thru Coating	Total Time Of Exposure	Remarks
368 A	Fiberglas 116-114	None	3M-X34932-C (EC 817 Type)	3 min.	6 min.	9 min.	At end of 3 min. - Scattered pitting at high speed end of leading edge. At end of 6 min. - Spec. A - Eroded through coating at high speed and low speed ends of leading edge. At end of 8 min. - Spec. B - Pitted along entire leading edge and through coating at edge of high speed and low speed clips. At end of 9 min. - Spec. A - Eroded through coating and 8-10 plies in scattered holes at high and low speed ends. Spec. B - Eroded through 2-3 plies at edge of high speed and low speed clips.
B	Sel. 5003			3 min.	8 min.	9 min.	
369 A	24ST Alclad	AN-TT-P-656	3M-X33030 + 5% Aluminum	3 min.	3 min.	4 min.	At end of 3 min. - Spec. A - Coating flaked off most of leading edge. Spec. B - Fine abrasion along entire leading edge. At end of 4 min. - Coating completely gone from leading edge of Spec. A. Spec. B - Coating flaked off leading edge at high speed and low speed ends.
B				3 min.	4 min.	4 min.	

TABLE NO. 14 (CONT.)

Specimen No.	Specimen Material	Primer	Topcoat	Time To Initiate Erosion	Time To Erode Thru Coating	Total Time Of Exposure	Remarks
370 A	24ST Alclad	AN-TT-P-656	3M-X231108 + 5% Aluminum	1 min.	3 min.	3 min.	At end of 1 min. - No erosion. At end of 3 min. - Spec. A - Coating flaked off entire leading edge. Spec. B - Coating flaked off 1" of leading edge at high speed end. Coating pitted along rest of leading edge.
B				1 min.	3 min.	3 min.	
371 A	24ST Alclad	AN-TT-P-656	3M-X34932-C (EC 817 Type)	3 min.	6 min.	10 min.	At end of 3 min. - Pitted along entire leading edge. At end of 6 min. - Increased pitting along leading edge with erosion through coating at high speed ends. At end of 10 min. - Eroded through coating for ¼" of leading edge at high speed end. Heavy pitting along leading edge with scattered holes through coating.
B				3 min.	6 min.	10 min.	
372 A	FS1H Magnesium	AN-TT-P-656	3M-X33030 + 5% Aluminum	2 min.	3 min.	5 min.	At end of 2 min. - Fine abrasion along entire leading edge. At end of 3 min. - Coating flaked off leading edge at high speed end. At end of 5 min. - Coating flaked off most of leading edge.
B				2 min.	3 min.	5 min.	
373 A	FS1H Magnesium	AN-TT-P-656	3M-X231108 + 5% Aluminum	2 min.	3 min.	3 min.	At end of 2 min. - Fine abrasion along leading edge. At end of 3 min. - Coating flaked from 3/4 of leading edge.
B				2 min.	3 min.	3 min.	

IG. Tests on Glass Reinforced Phenolic

Two sets of rain erosion test specimens were prepared by Warnken Engineering and Manufacturing Company's personnel, using 181-114 impregnated with heat resistant CTL-91 LD, which is a phenolic resin. The specimens numbered 563 and 564 were tested at 500 mph and 1"/hour rainfall.

The end of one minute exposure, at 500 mph, the resin was abraded off the leading edge and at the end of two minutes, erosion had progressed through the 1st ply of 181-114 fabric.

In general, a void free polyester laminate of 181-114 fabric will erode through the 1st ply of the fabric in one to one and one-half minutes at 500 mph and 1"/hour rainfall. The results obtained on the Phenolic specimens are considered similar to what is expected of uncoated plastic resin - glass fabric base specimens which are considered to have very poor resistance to rain erosion. The results on phenolic type resins are outlined in Table No. 15.

TABLE NO. 15
Rain Erosion of Coatings
500 M.P.H. - 1"/Hr. Rainfall
Tests on CTL-91-LD Phenolic Specimens

Specimen No.	Cloth	Resin	Fabricated By	Time To Initiate Erosion	Time To Erode Thru Coating	Total Time Of Exposure	Remarks
563 A	181-114	CTL-91-LD (Phenolic)	Warnken Eng. & Mfg. Co., Los Angeles, California	1 min.	2 min.	5 min.	At end of 1 min. - Resin surface pitted along leading edge. At end of 2 min. - Eroded through 1 ply of 181-114 cloth at high speed end. At end of 5 min. - Eroded through 2-3 plies of 181-114 cloth along entire leading edge.
B				1 min.	2 min.	5 min.	
564 A	181-114	CTL-91-LD (Phenolic)	Warnken Eng. & Mfg. Co., Los Angeles, California	1 min.	2 min.	3 min.	At end of 1 min. - Resin surface pitted along most of leading edge. At end of 2 min. - Eroded through 1 ply of cloth at high speed end. At end of 3 min. - Eroded through 1 ply of cloth along 3/4 of leading edge.
B				1 min.	2 min.	3 min.	

IH. Tests on Coast Paint & Chemical Company's System

A rain erosion resistant coating system consisting of Pro-Seal 581 primer and a two-part Pro-Seal 582 neoprene top coat with 582A accelerator was received from the Coast Paint and Chemical Company of Los Angeles.

The two sets of Fiberglas specimens #658 A & B and 659 A & B were prepared in the usual manner and given two brush coats of Pro-Seal 581 Primer with 1/2 hour air dry between coats. Eight brush coats of Pro-Seal 582, which was catalyzed in the ratio of 1 oz. of Part A accelerator per quart of cement, were applied. Each coat was allowed to air dry for 45 minutes and the coated specimens were air dried for 150 hours before testing. Examination of the coating after air drying 150 hours indicates that it was relatively soft, extensible, as compared to approved coatings, but tough material.

While the coating on specimens #658 A & B was ruptured at edge of high and low speed clamps at end of 40 minutes of testing, the rest of the leading edge of both specimens showed no sign of erosion.

Specimen #659 A withstood erosion tests for 75 minutes and specimen #659 B for 130 minutes before failing at the edges of the high and low speed clips. Although the coating on specimen #659 A was ruptured at the low speed end, at the end of 160 minutes of testing, the rest of the leading edge showed little or no sign of erosion.

On the basis of these tests on four specimens, this coating seemed promising in respect to rain erosion resistance. Therefore, for further study of this coating, specimens #662 A & B and 663 A & B were prepared by brushing on two coats of Pro-Seal 581 Primer with 1/2 hour air dry between coats. Eight brush coats of Pro-Seal 582 which was catalyzed in the ratio of four ounces per gallon of 582, part B accelerator, were applied. Each coat was allowed to air dry for 45 minutes before application of the next coat. The specimens were allowed to air dry seven days before testing. The specimens were evaluated at 500 mph and 1"/hour rainfall with the following results. The coatings on specimens #662 A & B and 663 A & B were ruptured at the high speed end of the specimens, at the edge of the clamp, due to flow of the soft, extensible neoprene coating. The coating bubbled slightly around the edge of the clamp, at first, and then the neoprene coating eroded through at the bubble in the range of 35 to 40 minutes. The specimens were run for a total of 75 minutes at which time the 1/8" laminate had eroded through to the blade. After the 75 minute run, the rest of the leading edge exhibited only slight signs of abrasion. These tests practically duplicate the previous results. The Pro-Seal 582 was comparable to the Gaco and Goodyear coatings in application and smoothness of finished coat. The Pro-Seal is somewhat slower drying, is so soft that it mars easily, and the film exhibits plastic flow under impact or compression loading.

It is recommended that the Pro-Seal 582 be reformulated to increase the tear strength and to make the film more resistant to plastic flow. A change of solvents to decrease the drying time is suggested.

It is believed that these changes will result in a satisfactory rain erosion resistant coating, meeting specification MIL-C-7439.

Goodyear Improved Neoprene Coatings

Six glass reinforced laminate test specimens were received from Goodyear Research Laboratory for evaluation. These specimens were prepared using two coats of Bostik 1007 as the primer. The top coats were of a specially formulated neoprene which were supposed to have greater erosion resistance than Goodyear 23-56. These specimens were given a Cornell Aeronautical Laboratory code number as follows:

C.A.L. Code No.	Goodyear Code No.
681 A	R-14L-23-370
B	R-14L-23-370
682 A	R-14L-23-371
B	R-14L-23-371
683 A	R-14L-23-372
B	R-14L-23-372

The specimens were then evaluated at 500 mph and 1"/hour rainfall. The results are outlined in bar graph on page 112. In general, all the specimens possessed erosion resistance equivalent to the current Goodyear 23-56 neoprene coating. These preliminary tests indicate that R-14L-23-372 had the best erosion resistance.

Douglas Coatings

Wright Air Development Center turned over four specimens coated by Douglas personnel at their Long Beach plant, with Douglas BP-101 primer and BP-102 solvent resistant top coat. This coating was tested at Douglas and was found to be satisfactory for rain erosion resistance on their tester. The coating as reported by Douglas was basically neoprene and had good solvent resistance.

These specimens, #698 A & B and #699 A & B were tested at 500 mph and 1"/hr. rainfall. In general, all four specimens failed through loss of adhesion in ten to fifteen minutes. Due to impact of the rain drops, the film then elongated and because of the inelastic nature of the film, bubbles were formed. These bubbles ruptured in twenty to twenty-five minutes.

The results are shown in Table No.16 and in Figure 9.

TABLE NO. 16
Rain Erosion of Coatings
500 M.P.H. - 1"/Hr. Rainfall
Tests on Douglas Aircraft Specimens

Specimen No.	Primer	Application	Topcoat	Thickness Coating (Mils)	Time To Initiate Erosion	Time To Erode Thru Coating	Total Time Of Exposure	Remarks
698 A	BP-101	Unknown	Douglas BP-101	10	25 min.	25 min.	50 min.	Coating failed through loss of adhesion with resulting bubbling along entire leading edge.
B					25 min.	25 min.	50 min.	
699 A	BP-101	Unknown	Douglas BP-101	10	25 min.	25 min.	41 min.	Coating failed through loss of adhesion with resulting bubbling along entire leading edge.
B					10 min.	10 min.	41 min.	

I-I. Tests on Metal Coatings

In order to aid Piasecki Helicopter Corporation in their study on method of preventing corrosion and rain erosion on metal helicopter rotor blades and assemblies, twenty rain erosion test specimens of 4130 steel, .060" thick, were prepared and shipped to Piasecki for the application of various surface treatments - zinc plating and various organic coatings.

Investigations at Piasecki of rotor blade corrosion prevention revealed that the protection provided by zinc plate alone proved inadequate. Corrosion protection of steel propeller blades involved the use of an organic coating over the zinc plate. Therefore, Piasecki personnel prepared test panels finished with zinc plate plus an additional protective medium and subjected them to salt spray tests. Also, in order to determine the effects of the elevated temperatures employed in bonding the rotor blade trailing edge assembly to the spars, samples of each finish included specimens heated to 325°F for one hour, in addition to unheated specimens. The materials tested in salt spray for corrosion included the following:

1. Zinc plate
2. Zinc plate, plus "Anozinc"
3. Zinc plate, plus "Anozinc", plus B-115 clear lacquer (United Chromium, Inc.)

Best corrosion resistance was achieved by finish number 3, which withstood salt spray exposure in excess of 300 hours without exhibiting corrosion. Corrosion became evident on finish number 1 and on finish number 2 after 41 hours. There was no apparent difference between those specimens which had been previously heated to 325°F and the unheated samples.

Based upon the above results, it will be noted that the system providing the best protection against corrosion employed an organic coating in addition to the plating. However, results on rain erosion to date indicate that lacquer or enamel is of little value as a protection against erosion. Information received on aircraft equipped with steel propellers utilizing zinc plate and lacquer coatings or enamel indicates that this type of finish requires stripping, replating, and refinishing after varied lengths of service. This practice would be highly undesirable if applied to rotor blades because of their size and lack of readily available facilities required for blade refinishing.

It has been determined from rain erosion data that a finish with a rubber-like outer surface offers the greatest promise for combined erosion and corrosion protection. With this in mind, Piasecki applied surface treatments and coatings on eighteen specimens and returned them to Cornell Aeronautical Laboratory, Inc., for erosion tests. The specimens were numbered A-1, 2 through J-1, 2 inclusive, and had the following finishing systems.

Cornell Aeronautical Laboratory Specimens #

620 A & B - A-1, 2	Zinc plate 1 mil thick
621 A & B - B-1, 2	Zinc plate plus black "Anozinc" plus B-115 black lacquer
622 A & B - C-1, 2	Phosphate coating, Spec. Jan-C-490 Grade 1 plus Bostik 1007, plus Gates N-700-9
623 A & B - D-1, 2	Vapor blast, plus phosphate coating, plus Bostik 1007, plus Gates N-700-9
624 A & B - E-1, 2	Phosphate coating, plus Bostik 1007, plus Goodyear 23-56
625 A & B - F-1, 2	Vapor blast, plus phosphate coating, plus Bostik 1007, plus Goodyear 23-56
626 A & B - G-1, 2	Zinc plate, plus Cronak, plus one coat of zinc chromate primer, plus two coats of silver gray blade enamel.
627 A & B - H-1, 2	Phosphate coating plus 3M-EC843, plus 3M-EC940
628 A & B - I-1, 2	Vapor blast plus phosphate coating, plus 3M-EC843, plus 3M-EC940
629 A & B - J-1, 2	Vapor blast steel surface, plus zinc plate 0.0004" to 0.0006", heat to 204°C for one hour, plus one coat phosphate treatment (Lithoform), plus one coat wash primer (MIL-C-153281), plus one coat Zinc chromate (MIL-P-6889), plus two coats black camouflage lacquer (MIL-1-6805)

The sources for the finish materials listed above are as follows:

B-115 lacquer	-	United Chromium, Inc., New York, N.Y.
Goodyear 23-56	-	Goodyear Tire & Rubber Co., Akron, Ohio
Gates N-700-9	-	Gates Engineering Co., Newcastle, Delaware
Bostik 1007	-	B. B. Chemical Co., Boston, Mass.
3M-EC843 and 3M-EC940	-	Minnesota Mining & Manufacturing Co., St. Paul, Minnesota
Silver gray enamel	-	Marshall Paint & Varnish Co., Newark, N.J.

Rain erosion tests were carried out on the twenty specimens at 500 mph and 1"/hour rainfall.

Results of Erosion Tests on Coatings for Rotor Blades

The results of the tests are outlined in Table No. 17 on page 68 and the specimens after test are shown in Figures 10 and 11.

Based upon these tests, it is apparent that lacquer or enamel coatings of normal thickness 0.5 to 1.5 mils will last from 1 to 3 minutes at 500 mph. The neoprene rubber coatings failed prematurely due to the loss of adhesion of the primer coat to the phosphate treated 4130 steel, with subsequent bubbling of the Gates N-79 and Goodyear 23-56. On aluminum and glass-reinforced laminates, these neoprene coatings in thickness of 9-10 mils will last from 70 to 100 minutes on an average unless there is loss of adhesion of the top coat to the primer or substrata.

TABLE No. 17

500 MPH 1"/ HR RAINFALL

RAIN EROSION TESTS OF ROTOR BLADE COATINGS

SPECIMEN NUMBER	SURFACE TREATMENT AND/OR PLATING	PRIMER COAT	TOPCOAT	TOTAL COATING THICKNESS MILS	RESULTS OF TESTS
620 A & B	ZINC PLATING (.001")	NONE	NONE	NONE	AT END OF 50 MIN. (SPEC A-2) SEVERAL SMALL HOLES THRU PLATING ALONG L.S. HALF OF L.E. AT END OF 110 MIN. (SPEC A-1) SEVERAL SMALL HOLES THRU PLATING AT H.S. END OF L.E. AT END OF 130 MIN. (SPEC A-1) SMALL CHIPS THRU PLATING ALONG L.E. (SPEC A-2) PLATING CHIPPED FROM L.E. IN 1/16" TO 1/8" HOLES ALONG L.E.
621 A & B B1, B2	ZINC PLATING (.001") BLACK ANOZINC (UNITED CHROMIUM, INC.)	NONE	B-115 LACQUER UNITED CHROMIUM INC.	1	AT END OF 1 MIN. CLEAR LACQUER COATING ERODED FROM 1" L.E. AT H.S.E. AT END OF 20 MIN. (SPEC B-1) SEVERAL FINE CRACKS THRU BLACK AND ZINC COATING FOR 1" OF L.E. TO H.S.E. AT END OF 30 MIN. (SPEC B-2) SMALL SCATTERED PITS THRU BLACK ANOZINC COATING AT H.S.E. OF L.E. AT END OF 150 MIN. (SPEC B-1) 3/4" STRIP OF PLATING ERODED FROM H.S.E. OF L.E. WITH SCATTERED PITTING ALONG REST OF L.E. (SPEC B-2) SMALL HOLES THRU PLATING: SCATTERED ALONG L.E. NOTE: BLACK ANOZINC AND ZINC PLATING ARE SEEMINGLY FUSED INTO ONE COAT MICROSCOPIC EXAMINATION SHOWS FINAL EROSION TO BE 4-5 MILS DEEP, AND IS ASSUMED TO BE THRU BOTH COATS
622 A & B C1, C-2	PHOSPHATE JAN-C-490 GRADE 1	BOSTIK 1007	GATES ENG. CO. N-79	8	AT END OF 10 MIN. (SPEC C-1) PIN HOLE THRU COATING 1" FROM H.S.E. AT END OF 16 MIN. (SPEC C-1) 2 HOLES (1/16"D) THRU COATING AT H.S.E. OF L.E. (SPEC C-2) COATING BUBBLED AND RUPTURED ALONG MOST OF L.E.
623 A & B D1, D-2	VAPOR BLAST PHOSPHATE	BOSTIK 1007	GATES ENG. CO. N-79	8	AT END OF 10 MIN. (SPEC D-1) COATING BUBBLED AND RUPTURED FOR 1" OF L.E. AT H.S.E. AT END OF 12 MIN. (SPEC D-2) COATING BUBBLED ALONG ENTIRE L.E. AND TORN FOR 1" TO H.S.E.
624 A & B E1, E-2	PHOSPHATE TREATMENT	BOSTIK 1007	GOODYEAR 23-56	8	AT END OF 25 MIN. (SPEC E-1) COATING BUBBLED AND RUPTURED FOR 1" OF L.E. TO H.S.E. AT END OF 30 MIN. (SPEC E-2) COATING BUBBLED AND RUPTURED FOR 1" OF L.E. TO H.S.E.
625 A & B F1, F2	VAPOR BLAST PHOSPHATE TREATMENT	BOSTIK 1007	GOODYEAR	8	AT END OF 28 MIN. (SPEC F-1) COATING BUBBLED AND PUNCTURED FOR 1/2" OF L.E. AT H.S.E. (SPEC F-2) COATING BUBBLED AND RUPTURED FOR 1" OF L.E. TO H.S.E. AT END OF 31 MIN. (SPEC F-1) COATING BUBBLED AND RUPTURED FOR 1" OF L.E. TO H.S.E.
626 A & B G1, G2	ZINC PLATING (.001") CROMAK TREATMENT	ZINC CHROMATE (MIL-P-6889A)	MARSHALL PAINT & VAR. CO. SILVER-GRAY BLADE ENAMEL	2	AT END OF 3 MIN. TOPCOAT AND PRIMER ERODED FROM 1/3 OF L.E. TO H.S.E. AT END OF 10 MIN. TOPCOAT AND PRIMER ERODED FROM ENTIRE L.E. AT END OF 100 MIN. SMALL PIT THRU ZINC COATING AT H.S.E. OF L.E. AT END OF 600 MIN. SCATTERED PITTING THRU PLATING ALONG ENTIRE L.E.
627 A & B H1, H2	PHOSPHATE TREATMENT	3M EC-843	3M EC-940	8-5	AT END OF 2 MIN. BLACK TOPCOAT ERODED FROM ENTIRE L.E. ERODED THRU COATINGS TO BASE METAL AT H.S.E. TO L.E.
628 A & B I1, I2	VAPOR BLAST PHOSPHATE	3M EC-843	3M EC-940	8-5	AT END OF 2 MIN. BLACK TOP COAT ERODED FROM ENTIRE L.E. SCATTERED PITTING THRU BASE COAT AT H.S.E. OF L.E.
629 A & B	VAPOR BLAST PHOSPHATE PLUS ZINC PLATING 0.0004 TO 0.0006	ZINC CHROMATE	BLACK LACQUER	1.5	AT END OF 3 MIN. ALL LACQUER & PRIMER COATING ERODED OFF AFTER 20 MIN. ZINC PLATING PITTED OFF 50% OF L.E.

The .001" of zinc plating will start to pit in the range of one to two hours and erosion of the zinc coating will increase up to about 10 hours. Specimens #626 A & B (G-1,2), having zinc plating and Cronak treatment plus zinc chromate and enamel, lasted for ten hours. It is questionable what caused the increase baking of the enamel at 250°F for 40 minutes.

The 3M coating system of EC-843 primer and EC-940 lasted for two minutes at 500 mph and 1"/hour rainfall.

On Specimens #629 A & B, which were received at a later date, the following results were obtained. At the end of the first minute of testing, the black lacquer had eroded off the entire leading edge to the primer. At the end of three minutes of testing, the zinc chromate and wash primer were removed from the leading edge. At the end of ten minutes testing the zinc plate showed signs of pitting off in areas fifty mils in diameter. This erosion progressed until the zinc plating was stripped off the entire leading edge at the end of twenty minutes. Figure 12 shows the specimens after twenty minutes of testing.

I-J. Fillers for Glass Laminates

For some time there has been a need for satisfactory fillers, putty, or similar material for filling in small pits, depressions, or minor damage caused by the rain erosion of the surface of glass reinforced polyester parts. There are numerous fillers on the market but they all have one or more unsatisfactory properties. In general, the oleo-resinous materials have good adhesion, outdoor durability, and relatively low shrinkage; however, they require twenty-four or more hours to dry. The lacquer type (nitrocellulose) dry hard for sanding in eight hours but have only fair adhesion to polyesters, are difficult to apply smoothly, and usually have a great deal of shrinkage and a relatively short outdoor life.

Two materials were examined: one, the oleo-resinous type, Tuf-On P-24 filler from Brooklyn Varnish Mfg. Company, Brooklyn, N. Y.; the second, Pyrox Putty, a lacquer type from the Avondale Company, Northfield, Illinois.

Two panels of glass reinforced polyester laminate were sanded to remove the glossy resin surface. A wet, ten mil film of each of the two materials noted above were put on the panels, using a doctor blade. A comparison of the two materials is shown in Table No. 18.

TABLE NO. 18

Comparison of Fillers for Glass Laminates

Material	Tuf-On P-24	Pyrox Putty
Application characteristics	Easy to apply and smooth	Difficult to apply skins over fast

Tack free time	4 hours	30 minutes
Time to become hard enough to sand	10 hours	4 hours
Time to become hard through 10 mil film	30 hours	10 hours
Shrinkage	12%	20%
Adhesion to laminate	Good	Fair
Lifting after brush application of Bostik 1007	No listing after 30 hrs. drying	No lifting after 10 hrs. drying

This investigation bears out past experience with these fillers and again shows the need for the development of a filler with the best properties of each type material.

IIA. Effect of Anti-icing Solution on Neoprene Coating

Numerous inquiries have been received regarding the effect of anti-icing solutions on the rain erosion resistance of neoprene coatings; therefore, preliminary tests were carried out on this aspect of the problem.

Specimens #601 and 602 were sanded and coated with a brush coat of Bostik 1007 primer. Specimens #601 was then coated with Goodyear 23-56 and Specimens #602 were coated with Gates N-79, so as to give a total film thickness of approximately ten mils. These specimens were then allowed to air dry for five days. The specimens were then immersed for twenty-four hours in the following anti-icing solution, as suggested by Lockheed Corporation's engineers, to simulate severe service test.

Ethylene Glycol C. P.	-	3 gallons
Water	-	2 gallons
Aerosol "OT" (Wetting Agent)	-	20 grams

After removal from this solution, the specimens were wiped dry and visually examined for signs of swelling or other deterioration. Within one-half hour of removal from the solution, the coatings were tested for rain erosion resistance at 500 mph and 1"/hour rainfall.

Visual examination of the coatings after twenty-four hours immersion showed some lightening in the color of the film, no swelling and no apparent softening when tested with the finger nail.

In general, neither the Goodyear 23-56 or Gates N-79 showed any decline in rain erosion resistance.

Based upon these tests and observations, it can be stated that under service conditions no difficulty should be experienced with parts covered with Gates N-79 or Goodyear 23-56 neoprene that are subject to anti-icing solutions of the type outlined above.

The results obtained are shown in Table No. 19 and in bar graph on page 113.

TABLE NO. 19
Rain Erosion of Plastics
500 M.P.H. - 1"/Hr. Rainfall
Effect of Deicing Solution on Rain Erosion
Resistance of Neoprene Coatings

Specimen No.	Primer	Topcoat	Drying Schedule	Treatment	Time To Initiate Erosion	Time To Erode Thru Coating	Total Time Of Exposure	Remarks
601 A	Bostik 1007 (Brush)	Goodyear 23-56 (Brush)	Air Dry 200 Hrs.	Immersed In Deicing Solution For 24 Hrs.	25 min.	50 min.	60 min.	At end of 25 min. - Spec. A- Coating finely abraded along leading edge. Light pitting at high speed end of leading edge. Spec. B - Light, scattered pitting at high speed end of leading edge. At end of 50 min. - Spec. A - Small hole through coating 1" from high speed end. At end of 60 min. - Spec. A - Eroded through coat and 3-5 plies for 1" of leading edge to high speed end. At end of 80 min. - Spec. B - Small hole through coat at high speed end. At end of 100 min. - Spec. B- Eroded through several plies in 4 small holes at high speed and low speed end of leading edge. Through 8-10 plies for 1/4" of leading edge to high speed end.
B					25 min.	80 min.	100 min.	

TABLE NO. 19 (CONT.)

Specimen No.	Primer	Topcoat	Drying Schedule	Treatment	Time To Initiate Erosion	Time To Erode Thru Coating	Total Time Of Exposure	Remarks
602 A	Bostik 1007 (Brush)	Gaco N-79 (Brush)	Air Dry 200 Hrs.	Immersed In Deicing Solution for 24 Hrs.	30 min.	70 min.	100 min.	At end of 30 min. - Light pitting along high speed end of leading edge. At end of 70 min. - Eroded through coating in small hole at high speed end of leading edge. At end of 100 min. - Spec. A - Coating bubbled for 1" of leading edge to high speed end. Eroded through 10-12 plies for 1/4" of leading edge to high speed end. At end of 140 min. - Spec. B- Small bubbles along 1" of leading edge to high speed end. Two holes 1/8" D through 10-15 plies at high speed end.
B					30 min.	70 min.	140 min.	

IIB. Effect of Elevated Temperatures on Coatings

The effect of heat on the erosion resistance of neoprene coatings Gaco N-79 and Goodyear 23-56 has been reported under the following conditions:

1. 180°F for 72 hours
2. 225°F for 72 hours
3. 300°F for 20 hours

The results of these tests indicate that heating for periods up to 72 hours at 180°F does not materially effect the erosion resistance. Heating for 72 hours at 225°F does effect the coating to some degree. In general, however, the presently approved coatings can be considered satisfactory after exposure to temperatures up to 200°F for periods in the range of 100 hours. As the temperature increases to 300°F, exposure for even shorter periods shows that these coatings are definitely unsatisfactory for rain erosion resistance.

However, under specification MIL-C-7439 (USAF) tests at 200°F for 20 hours are required. In addition, it was requested that tests be carried out on specimens coated with Gaco N-79 and Goodyear 23-56 exposed to 400°F for 10 minutes. Specimens were also to be tested by placing the coated laminate test specimens in the oven at 400°F and then holding them for an additional 10 minutes at 400°F.

The following specimens coated with Gaco N-79 and Goodyear 23-56 neoprene using the new Bostik primer 4764-27 were prepared.

Specimen No.	Material	Condition
547 A & B	Gaco N-79	Air dry 120 hrs.
548 A & B	Gaco N-79	Bake 20 hrs. at 200°F
545 A & B	Goodyear 23-56	Air dry 120 hrs.
546 A & B	Goodyear 23-56	Bake 20 hrs. at 200°F
557 A & B	Gaco N-79	Air dry 120 hrs. Bake at 400°F for 10 min.
558 A & B	Gaco N-79	Air dry 120 hrs. Bake at 400°F to equilibrium + 10 min.
559 A & B	Goodyear 23-56	Air dry 120 hrs. Bake at 400°F for 10 min.
560 A & B	Goodyear 23-56	Air dry 120 hrs. Bake at 400°F to equilibrium + 10 min.

After exposure at 200°F for 20 hours and then tested at 500 mph and 1"/hour rainfall, both Goodyear 23-56 and Gates N-79 specimens #545, 546, 547, and 548 showed

no apparent decrease in resistance to rain erosion and were considered satisfactory. The results obtained are shown in bar graphs on page 114 and 115 and in Tables No. 20 and 21.

Specimen #557 of Gaco N-79 and #559 of Goodyear 23-56 were allowed to air dry at room temperature for 5 days, than put in an oven held 400°F for 10 minutes.

The neoprene coating on all four specimens blistered very badly. Therefore, no further tests were carried out. Specimen #558 and #560 were air dried for 120 hours at room temperature, and then baked at 125°F for 12 hours to make sure all the residual solvent is removed from the neoprene coatings. Specimens #576 of Gaco N-79 and #579 of Goodyear 23-56 were prepared using Bostik 1007 primer and allowed to air dry for 100 hours. These specimens were then heated for 4 hours at 175°F to remove all the residual solvent. Specimens #558, 560, 576, and 579 were then put in a circulating air oven at 400°F for ten minutes. Upon removal of the specimens from the oven, specimens #558 and 560 showed slight blistering and #576 and 579 showed no blistering.

The four sets of specimens were then tested for rain erosion resistance at 500 mph and 1"/hr. rainfall. In testing, all the specimens failed primarily due to loss of adhesion of the neoprene coating to the glass laminate which caused bubbling along the leading edge and tearing loose of the coating along the sides of the specimen. Microscopic examination of the specimens indicated that Bostik primers 4754-27 and 1007 had probably lost their adherence to the glass laminate during the heating process. The neoprene coatings, however, appeared to have been made tougher by the curing at 175° and 400°F. The results are shown in Table No. 21 and in bar graph on page 116.

Further studies on the effect of heat treatment upon the rain erosion resistance of Gaco and Goodyear neoprene coatings at lower temperatures were carried out, under the conditions outlined below.

Specimen No.	Material	Condition
580 A & B	Goodyear 23-56	300°F for 10 min.
577 A & B	Gaco N-79	
581 A & B	Goodyear 23-56	375°F for 10 min.
578 A & B	Gaco N-79	
416 B	Goodyear 23-56	400°F for 10 min.
418 B		

Specimens #580 A & B and 581 A & B were coated with Bostik 1007 and Goodyear 23-56. Specimens #577 and 578 were coated with Bostik 1007 and Gaco N-79 at the same time and in the same manner as the preceding specimens. The four sets of specimens were air dried for 100 hours, baked for 4 hours at 175°F and then heated for 10 minutes at the temperature indicated above. The coating on the four sets of specimens was harder and darker in color after this heat treatment, but showed no signs of blistering.

Specimens #416 B and 418 B were brush coated by Goodyear personnel and returned to C.A.L. for testing. These two specimens were conditioned by heating at 175°F for

4 hours and then 400°F for 10 minutes. Although this coating changed from an olive color to almost black when heated at 400°F, no blistering was noticeable. All the above specimens were tested at 500 mph and 1"/hour rainfall. Specimens #416 B and #418 B, heat treated at 400°F, both failed through loss of adhesion. Specimen #416 B had most of the coating stripped off as an integral sheet at the end of 20 minutes testing. Specimen #418 B developed a 1/2" diameter bubble at the high speed end of the leading edge after 40 minutes of testing.

The coatings on the other 4 sets of specimens, heated at 300°F and 375°F all failed in 30 minutes of testing. Failure of all these heat treated specimens can be attributed, mainly to loss of adhesion of neoprene coating to the fiberglas laminate.

In general, the neoprene coatings appeared tougher, than normal, when cured at 175°F for 4 hours, and then at 300°F, 375°F, or 400°F for 10 minutes. Based upon the results and observations of the specimens used in these tests, it is believed that if a satisfactory adhesion system can be obtained between the neoprene and the glass reinforced laminate, the Goodyear 23-56 and Gaco N-79 coating should have satisfactory rain erosion resistance when exposed to an upper limit of 375°F for 10 minutes. Results of tests on heat treated neoprene coatings are shown in Table No. 22.

Four glass-reinforced erosion test specimens coated with heat resistant coating R-14L-27-86 were received from Goodyear Research Laboratory. This coating was formulated under Contract AF 18(600)110 which has as its objective the development of a coating that is rain erosion resistant and one that will withstand 500°F for thirty minutes. This Contract is also administered and monitored by the Materials Laboratory, Directorate of Research, Wright Air Development Center.

The samples were prepared by Goodyear personnel as follows: The specimens were sanded and given two brush coats of Bostik 1007 and 10-11 coats of R-14L-27-86 to give a total thickness of 10 mils. Considerable time was allowed between application of the R-14L-27-86 coating and before curing in a circulating hot air oven at 310°F for one hour.

Specimens prepared at Cornell Aeronautical Laboratory numbered 636 A & B and 637 A & B were sanded and given two brush coats of Bostik 1007 and allowed to air dry one hour before application of 8 brush coats of R-14L-27-86. Upon application of the first coat, the solvent in the R-14L-27-86 tended to wash off the Bostik 1007, if brushed too much. Extreme care had to be used to prevent the R-14L-27-86 coating from sagging since the solvents evaporated so slowly. The drying schedule was forty-five to fifty minutes between coats and overnight drying at room temperature, before baking one hour at 310°F.

Specimens #634 through 637 were tested at 500 mph and 1"/hour rainfall. The results are outlined in Table No. 23 on page 85 through 89 and in bar graph on page 117. Specimens #634 and 635 prepared by Goodyear are shown in Figure 13, after testing.

Analysis of the data obtained indicates that a 8-9 mil film of Goodyear R-14L-27-86 will resist erosion at 500 mph and 1"/hour rainfall for approximately 15 to 20 minutes when cured for 1 hour at 360°F. This is approximately one-quarter to one-third the average life of Goodyear 23-56 or Gates N-79.

Four more glass-reinforced erosion test specimens, fabricated from 116-114 glass cloth and Selectron 5003 resin, were sanded with #320 "wet or dry" paper, washed with toluol, and given two brush coats of Bostik 1007 and ten brush coats of Goodyear R-14L-27-86 Lactoprene Coating, for a total thickness of 10 mils. One-half hour air dry was allowed between coats, and specimens were air dried for 100 hours, to allow solvent escape before further treatment. Both sets of coated specimens were then cured for one hour at 310°F. Specimens #656 A & B were given an additional heat treatment for 1/2 hour at 500°F. After this cure period, the glass laminate specimens were charred and the coatings were almost completely covered with small blisters, approximately 20 mils in diameter. Specimens #657 A & B were not exposed to the 500°F heat treatment but were exposed for one week to a 95-98% relative humidity in a desicator, then immediately tested for rain erosion resistance. Specimens #656 and 657 were tested at 500 mph and 1"/hour rainfall. The results are outlined in Table No. 23.

During the 500°F cure of the R-14L-27-86 coating on Specimens #656 A & B, a gas was apparently released resulting in blisters of the lactoprene coating. The blistered coating was eroded off the leading edge of the laminate in 1/2 minute during the rain erosion test. The Goodyear Company was informed of the result, and arrangements have been made to get a high temperature resistant resin, which will be used in place of Selectron 5003 in fabricating the laminate specimens. These specimens will be coated with Goodyear R-14L-27-86, cured according to the same schedule and tested for rain erosion resistance.

The prolonged exposure of specimens #657 A & B to 95-98% relative humidity caused the coatings to soften, lose adhesion, and most of their rain erosion resistance. The specimens resisted rain erosion for only 5½ minutes before they bubbled and became badly pitted. Further heat resistant coatings developed from Lactoprene EV compounds by Goodyear Research Laboratory were applied to laminates of 116-114 impregnated with Selectron 5003 and Laminac PDL-7-669, by Goodyear personnel, as noted below. Bostik 1007 primer was used on all laminates.

689 A & B	-	R14L-27-126	694 A & B	-	R14L-27-142
690 A & B	-	R14L-27-127	695 A & B	-	R14L-27-142
691 A & B	-	R14L-27-127	696 A & B	-	R14L-27-148
692 A & B	-	R14L-27-128	697 A & B	-	R14L-27-148
693 A & B	-	R14L-27-128			

The Selectron impregnated specimens were evaluated at 500 mph and 1"/hour rainfall. Since most of these specimens failed due to loss of adhesion of the top coat, the Laminac PDL-7-669 impregnated specimens were not heated to 500°F for one-half hour, but tested as received. These specimens also failed rapidly primarily due to loss in adhesion. The detailed results of the tests are outlined in Table No. 24. The specimens were returned to Goodyear for their examination.

Further heat resistant materials studied by Goodyear included Teflon. In this study, Goodyear Research Laboratory personnel prepared six aluminum specimens coated with Teflon. A primer was sprayed on the aluminum and then a number of coats of Teflon emulsion paint, with fusing of each coat in an oven. The specimens were sent to Cornell Aeronautical Laboratory and were tested as follows: Specimens #684 A & B were evaluated for rain erosion resistance at 500 mph and 1"/hr. rainfall. Specimens #685 A & B were exposed outdoors for 3 months. Specimens #686 A & B are being exposed for one year.

Specimens #684 A & B had films of approximately ten mils which eroded from the high speed end in one minute and from the entire leading edge in two minutes. Specimens #685 A & B, after three months outdoor exposure, upon visual and macroscopic examination showed no signs of deterioration. After one minute, specimens #685 A & B had the film eroded off the high speed end similar to specimen #684. After one minute and three quarters, the film was eroded off four-fifths of the leading edge.

TABLE NO. 20
Rain Erosion of Coatings
500 M.P.H. - 1"/Hr. Rainfall
Effect Heat on Gaco N-79

Specimen No.	Topcoat	Drying Schedule	Time To Initiate Erosion	Time To Erode Thru Coating	Total Time Of Exposure	Remarks
547 A	Gaco N-79	Bake for 20 hrs. at 200°F	45 min.	70 min.	80 min.	At end of 45 min. - Scattered pitting at high speed end.
B			45 min.	90 min.	90 min.	At end of 80 min. - Spec. A - Two holes 3/32" D through coating and 5-10 plies of leading edge at high speed end. At end of 70 min. - Spec. A - Two small holes through coating at high speed end. At end of 90 min. - Spec. B - Heavy pitting of coating along leading edge. One pin hole through coating at high speed end.
548 A	Gaco N-79	Bake for 20 hrs. at 200°F	50 min.	90 min.	90 min.	At end of 50 min. - Light pitting at high speed end of leading edge.
B			50 min.	70 min.	80 min.	At end of 70 min. - Spec. B - Pitted through coating in small hole $\frac{1}{4}$" from high speed end. At end of 80 min. - Spec. B - 1/8" D hole through 8-10 plies $\frac{1}{4}$" from high speed end. At end of 90 min. - Spec. A - Heavy pitting along most of leading edge. Small hole through coating and 2-3 plies at high speed end.

TABLE NO. 20 (CONT.)

Specimen No.	Topcoat	Drying Schedule	Time To Initiate Erosion	Time To Erode Thru Coating	Total Time Of Exposure	Remarks
545 A	Goodyear 23-56	Bake for 20 hrs. at 200°F	30 min.*	50 min.*	60 min.*	At end of 30 min. - Spec. A - Coating pitted in patched area 1½" from low speed end. At end of 50 min. - Spec. A - Eroded through coating and 1 ply of patched area. At end of 55 min. - Spec. B - Light scattered pitting along leading edge. At end of 60 min. - Spec. A - Eroded through 10-15 plies in ¼" D hole in patched area. At end of 100 min. - Spec. B - Scattered pitting through coating at high speed end of leading edge.
B			55 min.	100 min.	100 min.	
546 A	Goodyear 23-56	Bake for 20 hrs. at 200°F	55 min.	90 min.	100 min.	At end of 55 min. - Light pitting at high speed end of leading edge. At end of 90 min. - Spec. A - Small bubble at high speed end of leading edge. At end of 100 min. - Spec. A - 1/8" D hole eroded through bubbled area and 5-10 plies at high speed end. Spec. B - Heavy, scattered pitting through coating at high speed end of leading edge.
B			55 min.	100 min.	100 min.	

* - Small area on leading edge of Specimen 545 A was damaged before coating was dry, and erosion was concentrated in this area.

TABLE NO. 21
Rain Erosion of Coatings
500 M.P.H. - 1"/Hr. Rainfall
Tests on Heat Treated Neoprene Coatings

Specimen No.	Primer	Topcoat	Thickness Coating (Mils)	Drying Schedule	Time To Initiate Erosion	Time To Erode Thru Coating	Total Time Of Exposure	Remarks
558 A	Bostik 4764-27	Gaco N-79	9	Air dry 400 hr. Bake: 4 hrs.-175°F 10 min.-400°F	15 min.	35 min.	35 min.	At end of 15 min. - Light scattered pitting at high speed end. At end of 35 min. - Spec. A- 1/16" D hole through coating, at high speed end. Coating bubbled and tore loose along side of specimen at high speed end. Spec. B - Scattered pitting along entire leading edge.
B			9		15 min.	-	35 min.	
560 A	Bostik 4764-27	Goodyear 23-56	10	Air dry 400 hr. Bake: 4 hrs.-175°F 10 min.-400°F	30 min.	110 min.	110 min.	At end of 30 min. - Coating finely pitted at high speed end of leading edge. At end of 110 min. - Several small holes through coating at high speed end. Coating tore loose along sides of both specimens.
B			10		30 min.	110 min.	110 min.	

TABLE NO. 21 (CONT.)

Specimen No.	Primer	Topcoat	Thickness Coating (Mils)	Drying Schedule	Time To Initiate Erosion	Time To Erode Thru Coating	Total Time Of Exposure	Remarks
576 A	Bostik 1007	Gaco N-79	7.5	Air Dry 100 Hr. Bake: 4 Hrs.-175°F 10 min.-400°F	20 min.	30 min.	40 min.	At end of 10 min.-Spec. B-Eroded through coating at edge of low speed clip. At end of 20 min.-Spec. A-Fine pitting of leading edge at high speed end. Spec. B - Fine pitting along 3/4 of leading edge. Coating loosened and rolled back at low speed end of leading edge. At end of 30 min.-Spec. A-Eroded through coating at edge of high speed clip. At end of 40 min.-Spec. A-Pitted along entire leading edge. 1/16" D hole through 2-3 plies at high speed end of leading edge.
B			7.5		10 min.	10 min.	20 min.	
579 A	Bostik 1007	Goodyear 23-56	5	Air Dry 100 Hr. Bake: 4 Hrs.-175°F. 10 min.-400°F.	10 min.	10 min.	10 min.	At end of 10 min.-Spec. A-Coating bubbled for 1" of leading edge at low speed end At end of 20 min.-Spec. B-Eroded through coating at edge of high speed clip. At end of 30 min.-Spec. B-Eroded through 10-15 plies at edge of high speed clip. Coating bubbled for 1" of leading edge at low speed end.
B			5		20 min.	20 min.	30 min.	

TABLE NO. 22
Rain Erosion of Coatings
500 M.P.H. - 1"/Hr. Rainfall
Tests on Heat Treated Neoprene Coatings

Specimen No.	Primer	Topcoat	Heat Treatment	Time To Initiate Erosion	Time To Erode Thru Coating	Total Time Of Exposure	Remarks
416 B	Bostik 1007	Goodyear 23-56	Bake 175°F for 4 hours. Bake 400°F for 10 min.	20 min.	20 min.	20 min.	At end of 20 min. - Loss of adhesion - coating stripped from most of specimen.
418 B	Bostik 1007	Goodyear 23-56	Bake 175°F for 4 hours. Bake 400°F for 10 min.	20 min.	40 min.	40 min.	At end of 20 min. - Few small pits at high speed end of leading edge. At end of 40 min. - 1/2" D bubble at high speed end.
577 A	Bostik 1007	Gaco N-79 (8 oz/gal N-300-9)	Air Dry 100 hrs. Bake 175°F for 4 hours Bake 300°F for 10 min.	20 min.	30 min.	30 min.	At end of 20 min. - Light pitting at high speed end of leading edge. At end of 30 min. - Spec. A - Coating bubbled for 1" of leading edge at high speed end. Spec. B - Eroded through coat at edge of high speed clip. At end of 40 min. - Spec. B - Coating bubbled for 1" of leading edge to high speed end.
B				20 min.	30 min.	40 min.	
580 A B	Bostik 1007	Goodyear 23-56	Air Dry 100 hrs. Bake 175°F for 4 hours. Bake 300°F for 10 min.	20 min.	30 min.	40 min.	At end of 20 min. - Scattered pitting at high speed end. At end of 30 min. - Eroded through coating at edge of high speed clip. At end of 40 min. - Spec. A - Eroded through 15-20 plies at edge of high speed clip. Spec. B - Bubbled at high speed end and 1/4" D hole through 8-10 plies at high speed end.

TABLE NO. 22 (CONT.)

Specimen No.	Primer	Topcoat	Heat Treatment	Time To Initiate Erosion	Time To Erode Thru Coating	Total Time Of Exposure	Remarks
578 A	Bostik 1007	Gaco N-79 8 oz/gal N-300-9	Air Dry 100 Hrs. Bake 175°F for 4 hours. Bake 375°F for 10 min.	20 min.	30 min.	40 min.	At end of 20 min. - Light pitting along 1/2 of leading edge to high speed end. At end of 30 min. - Eroded through coating at edge of high speed end. At end of 40 min. - Spec. A - Eroded through 10-15 plies 1/4" to high speed end.
B				20 min.	30 min.	40 min.	
581 A	Bostik 1007	Goodyear 23-56	Air Dry 100 Hrs. Bake 175°F for 4 hours. Bake 375°F for 10 min.	20 min.	30 min.	45 min.	At end of 20 min. - Fine pitting at high speed end of leading edge. At end of 30 min. - Eroded through coating at edge of high speed clip. At end of 45 min. - Eroded through 15-20 plies at high speed end of leading edge.
B				20 min.	30 min.	45 min.	

TABLE NO. 23
Rain Erosion of Coatings
500 M.P.H. - 1"/Hr. Rainfall
Tests on Goodyear R14L-27-86 Lactoprene Coating

Specimen No.	Coated By	Primer	Topcoat	Drying Schedule	Thickness Coating (Mils)	Time To Initiate Erosion	Time To Erode Thru Coating	Total Time Of Exposure	Remarks
634 A	Goodyear	Bostik 1007	Goodyear R14L-27-86	No air drying schedule given. Final cure 310°F for 1 hour.	10	10 min.	20 min.	22 min.	At end of 10 min.- Fine pitting along leading edge. At end of 20 min.- Small bubbles at high speed end of leading edge. Small hole through coating 1" from high speed end. At end of 22 min 1/4" D holes through 2-3 plies at high speed end of leading edge.
634 B						10 min.	15 min.	17 min.	At end of 10 min. Fine pitting along leading edge. Small bubble at low speed end of leading edge. At end of 15 min.- Bubbles ruptured at high speed and low speed end of leading edge. At end of 17 min.- Eroded through 5-8 plies in 1/2" D holes at high and low speed end of leading edge.

TABLE NO. 23 (CONT.)

Specimen No.	Coated By	Primer	Topcoat	Drying Schedule	Thickness Coating (Mils)	Time To Initiate Erosion	Time To Erode Thru Coating	Total Time Of Exposure	Remarks
635 A	Goodyear	Bostik 1007	Goodyear R14L-27-86	No air drying schedule given. Final cure 310°F for 1 hour	9	6 min.	10 min.	20 min.	At end of 6 min.- Fine pitting at high speed end of leading edge. At end of 10 min.- Eroded through coating at edge of low speed clip. At end of 20 min.- Severe erosion at low speed end of leading edge. 1/4" D hole through 3-5 plies at high speed end of leading edge.
635 B						6 min.	10 min.	15 min.	At end of 6 min.- Small bubble 1" from low speed end. Fine pitting at high speed end. At end of 10 min.- Bubble at low speed end ruptured - pitted along entire leading edge and bubbled in center of leading edge. At end of 15 min.- Eroded through 8-10 plies in 1/2" holes in bubbled areas.

TABLE NO. 23 (CONT.)

Specimen No.	Coated By	Primer	Topcoat	Drying Schedule	Thickness Coating (Mils)	Time To Initiate Erosion	Time To Erode Thru Coating	Total Time Of Exposure	Remarks
637 A	C.A.L.	Bostik 1007 Brush-2 coats	Goodyear R14L-27-86 Brush-8 coats	Air Dry 45-50 min. between coats Final cure at 310°F for 1 hour	10	10 min.	15 min.	16 min.	At end of 10 min.- Coating pitted along leading edge. At end of 15 min.- Eroded through coating in several small holes at high speed end and at low speed end. At end of 16 min.- 1/2" hole through 3-5 plies at low speed and at high speed ends.
637 B						10 min.	13 min.	16 min.	At end of 10 min.- Scattered pitting along high speed end of leading edge. At end of 13 min.- Coating pitted along entire leading edge. Small hole through coat at high speed end. At end of 16 min.- 1/2" D hole through 2-3 plies at high speed end of leading edge.

TABLE NO. 23 (CONT.)

Specimen No.	Coated By	Primer	Topcoat	Drying Schedule	Thickness Coating (Mils)	Time To Initiate Erosion	Time To Erode Thru Coating	Total Time Of Exposure	Remarks
636 A	C.A.L.	Bostik 1007 Brush-2 coats	Goodyear R14L-27-86 Brush-8 coats	Air Dry 45-50 min. between coats Final cure at 310°F for 1 hour	10	10 min.	15 min.	16 min.	At end of 10 min.- Scattered pitting along leading edge. At end of 15 min.- Pitted along entire leading edge - 2 small holes through coating at high speed end. At end of 16 min.- 1/8" D hole through 3-4 plies at high speed end of leading edge.
636 B						10 min.	13 min.	16 min.	At end of 10 min.- Coating pitted at high speed end, of leading edge. At end of 13 min.- Pitted along entire leading edge. Small bubble 1" from high speed end. At end of 16 min.- 4 holes 1/8" D through 2-3 plies at high speed end of leading edge.

TABLE NO. 23 (CONT.)

Specimen No.	Coated By	Primer	Topcoat	Drying Schedule	Thickness Coating (Mils)	Time To Initiate Erosion	Time To Erode Thru Coating	Total Time Of Exposure	Remarks
656 A	C.A.L.	Bostik 1007	Goodyear R14L-27-86 (Brush-10 coats)	Cure: 1 hr. at 310°F 1/2 hr. at 500°F	10	Less than 30 seconds	Less than 30 seconds	30 sec.	Before test - Leading edges of both specimens covered with small blisters At end of 30 sec. Blisters ruptured and coating eroded off entire leading edge.
B									
657 A	C.A.L.	Bostik 1007	Goodyear R14L-27-86 (Brush-10 coats)	Cure: 1 hr. at 310°F. - conditioned for 7 days at 95-98% relative humidity, then tested immediately.	10	5 min.	$5\frac{1}{2}$ min.	$5\frac{1}{2}$ min.	Before test - Coating very soft and pliable. At end of 5 min.- Spec. A - Leading edge abraded mostly at high speed ends. Spec.B- 1" hole at high speed end. At end of $5\frac{1}{2}$ min.- Spec. A - 2 pin holes at high speed end. Coating on outer half of leading edge lifted from laminate. Spec.B- Coating on outer half of leading edge lifted from laminate.
B						5 min.	$5\frac{1}{2}$ min.	$5\frac{1}{2}$ min.	

TABLE NO. 24
Rain Erosion of Coatings
500 M.P.H. - 1"/Hr. Rainfall
Goodyear Lactoprene EV Compounds

C.A.L. Specimen	Goodyear Specimen No.	Primer	Laminate Resin	Topcoat	Thickness Coating (Mils)	Time To Initiate Erosion	Time To Erode Thru Coating	Total Time Of Exposure	Remarks
689 A	3	Bostik 1007	PDL 7-669	R14L-27-126	8.0	1 min.	1 min.	2½ min.	Coating bubbled and ruptured at high speed end.
B	4				7.5	1 min.	2 min.	2½ min.	
690 A	5	"	Selectron 5003	R14L-27-127	10.0	8 min.	10 min.	12 min.	Eroded through coating and several plies in scattered holes along leading edge.
B	6				9.0	10 min.	12 min.	16 min.	
691 A	7	"	PDL 7-669	R14L-27-127	9.5	6 min.	8 min.	10 min.	Coating bubbled and ruptured along leading edge.
B	8				9.0	3 min.	5 min.	6 min.	
692 A	9	"	Selectron 5003	R14L-27-128	10.0	6 min.	9 min.	11 min.	Eroded through coating and several plies in 1/2" D hole at high speed end.
B	10				10.0	6 min.	9 min.	11 min.	Coating bubbled and ruptured at low speed end of leading edge.
693 A	11	"	PDL 7-669	R14L-27-128	9.0	2 min.	2 min.	3 min.	Eroded through coating and several plies in 1/2" D hole at high speed end.
B	12					4 min.	8 min.	9 min.	
694 A	13	"	Selectron 5003	R14L-27-142	9.0	2 min.	2 min.	3 min.	Coating bubbled and ruptured for 1/2 of leading edge to high speed end.
B	14					2 min.	3 min.	3½ min.	Coating bubbled and ruptured along entire leading edge.

TABLE NO. 24 (CONT.)

C.A.L. Specimen	Goodyear Specimen No.	Primer	Laminate Resin	Topcoat	Thickness Coating (Mils)	Time To Initiate Erosion	Time To Erode Thru Coating	Total Time of Exposure	Remarks
695 A	15	Bostik 1007	PDL 7-669	R14L-27-142	9.0	1 min.	1 min.	2 min.	Coating bubbled and ruptured along most of leading edge.
B	16					1 min.	1 min.	2 min.	
696 A	21	"	Selectron 5003	R14L-27-148	9.0	6 min.	9 min.	9 min.	Coating bubbled and ruptured at high speed end of leading edge.
B	22					2 min.	2 min.	3 min.	
697 A	23	"	PDL 7-669	R14L-27-148	10.5	1 min.	3 min.	4 min.	Coating bubbled and ruptured at high speed end of leading edge.
					10.0	4 min.	4 min.	5 min.	

Section III

Studies on Mechanism of Rain Erosion

IIIA. Influence of Hardness on Erosion Resistance

Six rain erosion test specimens were fabricated from a substitute for 4130 steel, known as 8630. The specimens were processed as described below to achieve different hardnesses. It was believed that an investigation of the influence of hardness on the erosion resistance of a specific material might give further indication as to the nature of the erosion.

To prevent the steel surface from oxidation and decarburization during heat treatment, a copper plating approximately 0.002 inch in thickness was applied to five of the specimens.

TABLE NO. 25

8630 Steel Rain Erosion Specimens

Specimen No.	Method of Heat Treatment	State After Heat Treatment	Rockwell C Hardness
605	Annealed at 1550°F for 15 minutes - Cooled in Silicel	Annealed Tensile 80,000 psi	13
606	Normalized at 1550°F for 15 minutes - air cooled	Normalized Tensile 110,000 psi	20
607	Heated to 1550°F for 30 minutes - oil quenched. Tempered for 60 minutes at 850°F	Hardened Tensile 156,000 psi	33
608	Heated to 1550°F for 30 minutes - oil quenched. Tempered for 60 minutes at 800°F	Hardened Tensile 180,000 psi	39
609	Not copper plated. Surface hardened to .010" by carburizing in liquid bath at 1650°F for 60 minutes oil quenched.	Hardened surface	64
610	Normalized at 1550°F for 15 minutes - air cooled	Shotpeened	Surface work hardned - but not measurable

After heat treatment, the copper coating was removed from the steel. Electrolytic stripping was carried out in an aqueous solution of sodium cyanide and sodium hydroxide at 6 volts and 15 amps. with the copper plated specimen as the anode. Because the removal of copper was rather slow and non-uniform by this method, it was abandoned in favor of chemical stripping with a concentrated chromic acid solution acidified with sulfuric acid.

Since it has been reported (reference 16) that metals that have been shotpeened have greater fatigue life, it was believed desirable to include such a specimen in this series to determine if this process had any influence on rain erosion which is thought to be an impact fatigue phenomena. The specimen was shotpeened at a local General Motors' plant. The method consists of pelting the steel with fine round shot propelled by air pressure. The steel shot used was a #28 shot, .018 to .024 inches in diameter. This shotpeening is said to cause plastic flow of the metal and to set up a high residual compressive stress in the surface. The cold, forged surface was estimated to be approximately 0.008 inches in depth.

The specimens were tested at 500 mph and 1"/hour rainfall. They were tested in a manner similar to that used and previously reported for plastic specimens. In performing this test the specimens were eroded on the testing machine until the 50% erosion initiation point occurred along the leading edge. This stage of erosion can be defined as an area where approximately 50% of the eroded surface is covered with fine pits and the remaining 50% of the area is unpitted. The 50% initiation point located by microscopic examination at a low power, either 12x or 30x, and the radius of the arm at this point was determined. From the radius and the speed of rotation, the velocity of the specimen at the 50% initiation point was computed. From the velocity and the rainfall rate, the number of raindrop impacts per sq. in. were estimated. This estimation on the steel specimens is considered to be less accurate than on the previous plastic specimens. The character of erosion is somewhat different from that on plastics. Perhaps if many steel specimens were tested and one became familiar with their characteristics, one could recognize variations, one from another, with greater precision than on these first few specimens. For two of the specimens, #606 and #608, the 50% erosion point was estimated as slightly off the specimen on the high speed end; that is, the time of exposure was a little short for the observation. The first four specimens, #605 through #608, all showed a roughening in which metal was pushed up (above the initial surface) around the erosion pits. This was observable both visually and tactilely. This effect was not present on the carburizing specimen. (#609)

For comparison with the previously tested plastic specimens, the results are plotted in Figure 14, page 132, which shows the line obtained from tests on polymethylmethacrylate. It may be seen that at 500 mph, the group of steel specimens require about 1800 times more impacts per sq. in. to produce the same erosion when compared with polymethylmethacrylate.

The increase in hardness from 13 to 39, in the group of four specimens hardened by quenching, appears to have a beneficial influence in producing resistance to rain erosion. The added hardness obtained by carburizing, however, did not produce a corresponding increase in resistance. These observations are general, since, further tests of steel specimens should be carried out to observe the consistency of the results.

With the polymethylmethacrylate specimens, a wide range of velocities was obtained in the tests. A similar range in velocity appears difficult or impossible with steel specimens. Were the velocity much reduced from that used in these tests, the time for erosion would become very great. The velocity cannot be very much increased over that used due to the weight of the metal specimens and centrifugal forces. It appears more profitable to explore further the influence of properties. Such information may consist of testing a group of steels whose hardness is varied and whose ductility varies. Unfortunately, other properties, such as chemical composition would probably vary within such a group. Work with metallurgists in the selection of such groups is planned.

TABLE NO. 26

8630 Steel Specimens After Erosion

Specimen No.	Estimated Radius at 50% erosion point	Velocity at 50% erosion point	Time of exposure	Total impacts per sq. inch at 50% erosion point
605	24.5	515	20 hrs.	3,140,000
606	26.5	570	20 hrs.	3,480,000
607	24.0	510	30 hrs.	4.670,000
608	26.5	563	30 hrs.	5,150,000
609 carburized	24.3	515	30 hrs.	4,710,000

Specimen #610, shown in Figure No.16 was the shot peened specimen which showed a markedly higher rate of erosion. This was probably due to the roughness of surface. The smaller craters or roughness due to shot peening became larger and deeper after the first hour of testing. After eight hours, the entire leading edge was badly pitted.

IIIB. Influence of Type of Material on Erosion

A survey, to date, of all types of materials has indicated that common glass apparently has satisfactory rain erosion resistance up to speeds of 500 mph. With this in mind, attempts were made to bond special thin foils of glass 8 to 10 mils in thickness to fiberglas reinforced laminates. This glass foil was obtained from Corning Glass Research Laboratory at Corning, New York. The bonding agents used were Araldite adhesives, developed by Ciba Corporation. This preliminary attempt ended in failure due to the extreme brittleness of the glass foil which cracked or shattered with very slight shock to the covered laminate specimen. Another approach that appeared to have greater merit was to disperse small glass beads in polyester resin. These beads are manufactured in a large range of sizes from 5 mils up to 50 mils by Minnesota Mining and Manufacturing Co., under the name of "Superbrite" bead. After dispersion in the polyester resin, the surface of a wet laminate and glass beads cured as an integral unit. This system was not successful since the bead layer was two to three layers in thickness and the beads had poor adhesion to the laminate. It was decided to standardize

on two sizes of glass beads, 18-20 mil and 25-30 mil. The beads were dispersed in cold setting Araldite adhesive #101 of the epoxy type and a layer of one glass bead in thickness was coated on glass laminate specimens.

Microscopic examination of specimens #549 A & B showed that specimen A had a uniform single layer of glass beads of 18-20 mil thickness bonded to the glass laminate and specimen B had a single uniform layer of glass beads of 25-30 mil thickness bonded to the specimen. After testing at 500 mph and 1"/hour rainfall for 1 minute, the Araldite film on specimen #549 A, with the smaller beads, had peeled off in large areas indicating loss of adhesion. Specimen #549 B with the beads of 25-30 mil in diameter did not show any signs of failure for 2 minutes. The failure was due to the beads chipping loose from the Araldite and allowing small erosion pits to take place in the glass laminate. This preliminary test indicates that this system may have merit if optimum size glass beads are used and a satisfactory bonding agent can be obtained for bonding the glass beads to aluminum or glass reinforced laminates. The evaluation of other adhesives with the 25-30 mil glass beads is planned.

IIIC. High Speed Erosion Tests

Since the present trend in missile and aircraft design is toward higher supersonic flight speeds, the phenomena of erosion at supersonic velocities are of considerable interest. An analytical approach to the problem led to the belief that at higher Mach numbers the shock waves might tend to prevent rain erosion by splitting up or pushing aside the water droplets. However, it was postulated that the type of airfoil would influence the results so radically that no accurate prediction could be made. It was suggested that ogives might be fired vertically through rain at supersonic speeds as a preliminary approach to the problem. Since Army Ordnance has a standard system to retrieve ogives, this project was considered practical.

A program was worked out in conjunction with the Army Ordnance and Picatinny Arsenal. The tests will be conducted at an Army Ordnance Proving Ground, using an M303 H.E. Shell. Cornell Aeronautical Laboratory designed the metal insert and plastic ogive nose for this 57 mm shell. The metal insert of 24ST aluminum, and configuration of the plastic ogive to be used in the preliminary tests are shown in Figure 17, page 135. Fifty 24ST aluminum inserts were machined, as well as a mold for the glass reinforced plastic ogive. Figures 18 and 19 show the mold, metal insert, and the completed plastic ogive shape. Twenty-five inserts were submitted to the Plastics Section at Picatinny Arsenal for preparation of the specimens they would like tested. Methods of molding pigmented, glass reinforced, alkyd resins were studied and the following technique was evolved.

A transfer type mold used with Plaskon's alkyd molding compound #442, which is a polyester containing pigment and reinforcing glass fibers. Small preforms cylindrical in shape and weighing 75 grams were formed by prewarming at 125°F and pressing in the cylinder of the transfer mold. The metal insert was then screwed into the transfer section of the mold. The preform and transfer portion of the mold was then heated to 275°F. The bottom portion of the mold was then put together with the transfer part of the mold into a small press held at 325°F and the press closed so as to give approximately 100 psi on the ram of the transfer cylinder. The molded ogive was then allowed to cure for five minutes after the mold had reached 310°F.

Two plastic ogives were delivered to the Ordnance Department at the Pentagon, for preliminary firing tests at Aberdeen. These two plastic ogives were fired without rainfall to determine whether they were structurally staisfactory. The tests carried out indicated that the ogives were satisfactory.

Based on these satisfactory results the following twenty materials will be evaluated. The first 12 sets will be molded at Picatinny since they are of interest to that facility and the rest by Cornell Aeronautical Laboratory.

1. Lucite or Plexiglas 2. Cellulose Acetate 3. Cellulose Acetate Buturate 4. Ethyl Cellulose 5. Kralastic 2186-3 6. Modified Polystyrene 7. Polystyrene	1/8" x 6" x 6" Sheet- Minimum requirement for 2 specimens.
8. Class 6 - M.I.L. - P-10420 - Hi-Imp. Strength Cord Filled Phenolic 9. Class 3 - M.I.L. - P-10420 - General Purpose Cotton Flock Filled Phenolic 10. Durez - 13348 - Modified Phenolic - Modified Polyacrylonitrile Rubber	2-3# of each material and curing cycle
11. Neoprene Rubber - 50 Durometer - M.I.L. - R-3065 12. Neoprene Rubber - 90 Durometer - M.I.L. - R-3065	Uncured stock & curing cycle

13. Pigmented Resin, reinforced with glass fibers
14. Woven glass reinforced laminate - polyester
15. Woven glass reinforced laminate - phenolic
16. Polyester - reinforced glass fiber molding coated with 10 mils Goodyear 23-56 neoprene
17. Same material, coated with 10 mils Gates Engineering N-79 neoprene
18. Same material, coated with 10 mils Goodyear anti-static or heat resistant coating
19. Same material, coated with 10 mils of vinyl coating
20. Same material, coated with 3-4 mils of a hard, phenolic coating such as Inter-Chemical Company's 4A Drum liner.

The specifications on these materials are as follows:

1. Lucite
   H.M. 140 Type I - Class A - M.I.L. P-10421

2. Plexiglas VM-5688
   Type I - Class A - M.I.L. P-10421

3. M.I.L. - P-10407
   Type II - Class 6 - Tenite II H-2

4. A.X.S. - 1762
Type I - Grade 5
ECX 441 - Hercules Powder Company

5. M.I.L. - P-10408
Type II - Grade 7
XM-H3 "Lumarith" Cellanese Corp. of America
Hercocel 12681
Tenite I HZ

6. PA-PD-72 Polystyrene Modified

7. Polystyrene PA-PD-108
Type I - General Purpose

8. Fiberite #1111
Fiberite Corporation
Winona, Minnesota
Att'n: Mr. John E. David

BM 16468
Bakelite Division
Union Carbide & Carbon Corp.
New York 17, New York
Att'n: Mr. Honish

9. Durez #1554
G.E. 12401

13. Plaskon #442

14. 181-114 with Selectron 5003

15. 181-114 with CTL-91 resin

16. (
17. (
18. (Plaskon #442
19. (
20. (

For the initial study, it was decided that the 1/4" radius for the ogive would be the best airfoil since it would correspond to the 1/4" radius on the current rain erosion test specimen. Cornell Aeronautical Laboratory will study those materials that have not been studied on the current test apparatus at subsonic speeds of 500 to 600 mph.

Insofar as possible, the following data will be reported.

1. Materials tested
   a) Type, grade
   b) Manufacturer
   c) Method of molding

2. Velocity at which tested

3. Amount of rain during test

4. Time of flight or exposure to rainfall
   a) Maximum height attained

5. Quantitative method of evaluation of rain erosion insofar as such measurements are practicable.

Methods of molding CTL-91LD-glass-reinforced and Selectron 5016-glass reinforced ogives were evolved. The sixteen specimens to be prepared by C.A.L. were fabricated and coated, as outlined below and were forwarded to the Ordnance Department, at the Pentagon.

Specimen No.	Material	Coating
13 A & B	Plaskon #442	None
14 A & B	116-114 glass- Selectron 5016, polyester	None
15 A & B	181-114 glass- CTL-91LD, phenolic	None
16 A & B	Plaskon #442	Bostik 1007 primer Goodyear 23-56
17 A & B	Plaskon #442	Bostik 1007 primer Gates N-79
18 A & B	Plaskon #442	Bostik 1007 primer Goodyear 23-56 Goodyear R-14L-23-296 Anti-static coating
19 A & B	Plaskon #442	Polyprene Enamel TP-54-35 Inter Chemical Corp.
20 A & B	Plaskon #442	Inter Chemical Corp. 4 A Drum liner

It is planned that the specimens with the "A" designation be tested at a Mach number of 1.5, and those with the "B" designation at a Mach number of 2.75. Insofar as possible, each set will be fired through rainfall of the same concentration.

Picatinny has designed the molds for the twelve sets of ogives they are to fabricate.

SECTION IV

Test Apparatus

IVA. Maintenance of Equipment

After the whirl test blade had been in use for eighteen months with little maintenance other than polishing with steel wool and the installation of new stainless steel clips, it was decided that the test blade should be overhauled. The high speed end of the blade with the aluminum trailing edge had deposits of calcium salts that were almost 1/16" in thickness and very hard and brittle, similar to boiler scale. The appearance of the blade is shown in Figure No. 20. Upon removal of this scale it was found that the aluminum in the area where it made a butt joint with the steel portion of the blade had eroded badly. In addition, the stainless steel clips that held the specimen as well as the tip of the blade were eroded to such a degree that they were collapsing. The chrome plating on the underside of the blade was pitted and pin point areas of rust were observed. The blade was sent into the shop for removal of the aluminum trailing edge so that the copper and chrome plating could be stripped and the blade replated.

After the eroded areas of the leading edge and tip of the 4130 blade had been carefully polished to proper contour, so as to remove most of the pits due to erosion, the blade was replated. New stainless steel clips were made and assembled on the blade. The aluminum trailing edge was welded with aluminum to fill in the roughened surfaces as much as possible and riveted to the steel blade. It seemed desirable that a new aluminum trailing edge be made to replace the old one but due to the press of higher priority work, it was estimated that it would take six to eight weeks to have one fabricated. Since the test apparatus had been out of operation for nearly six weeks it was decided that additional periods of non-operation were out of the question.

A new solenoid valve that controlled the rainfall was installed since the old valve exhibited a tendency to stick open. The nozzle for producing rain was also cleaned and checked. After some trouble in producing uniform rain drop size, it was found that a piece of scale had lodged behind the nozzle during the cleaning operation. This was removed and the test apparatus was put back into operation.

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APPENDIX

A. RAIN EROSION OF COATINGS

TEST CONDITIONS:

AVERAGE SPEED: 500 M.P.H.
ONE INCH PER HOUR RAIN FALL

0° ANGLE OF ATTACK
MEDIAN DROPLET SIZE 1.9 M M

NO EROSION

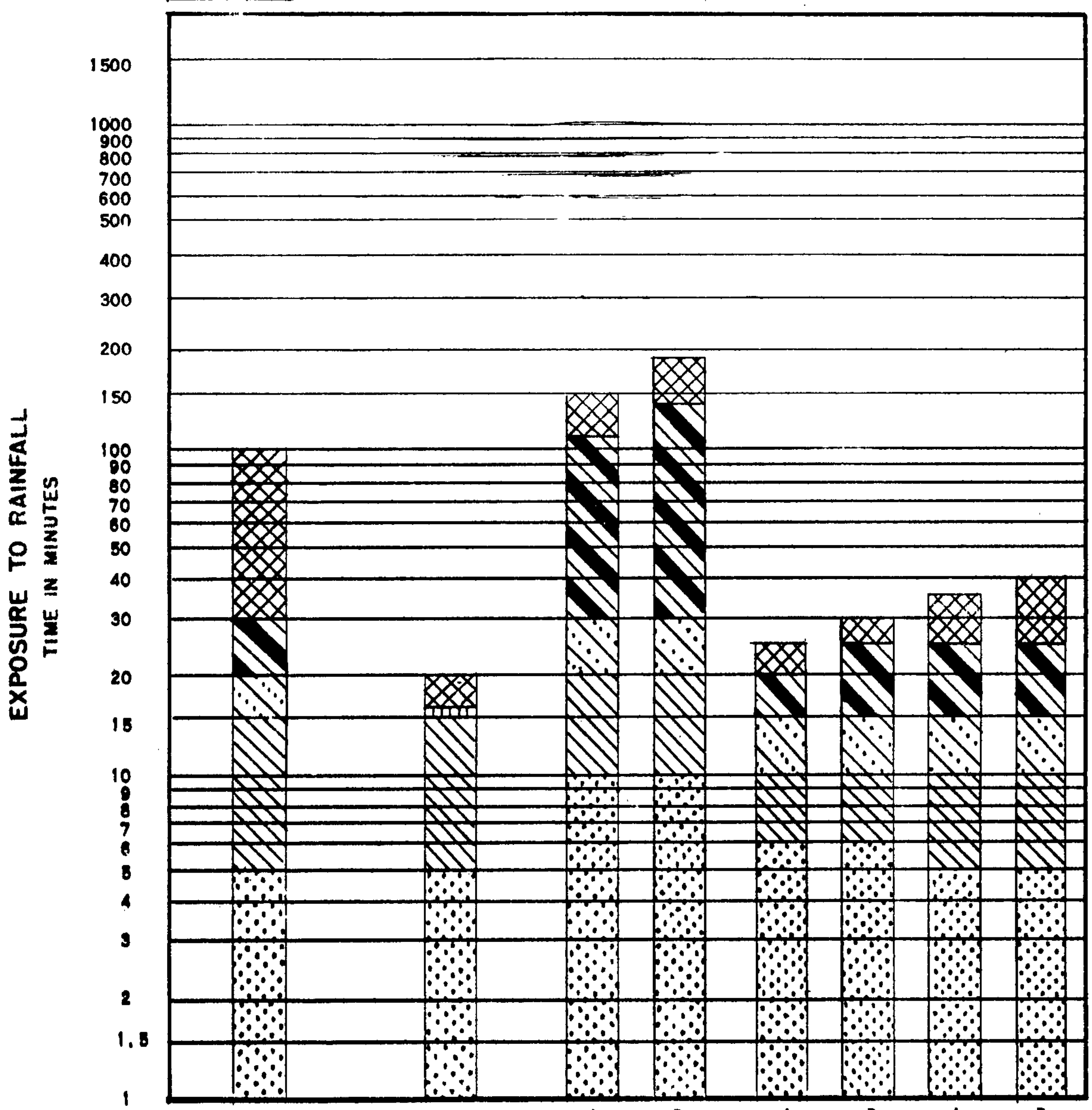
COATING ABRADED AT HIGH SPEED END

COATING PITTED ALONG LEADING EDGE

EROSION THRU COATING AT HIGH SPEED END

THRU COATING & FIRST PLY OF CLOTH

FAILURE POOR ADHESION



SPECIMEN NO.	419 A	422 B	487	536	553
PRIMER	BOSTIK 1007	BOSTIK 1007	BOSTIK 1007	BOSTIK 1007	BOSTIK 4764-27
TOP COAT	GOODYEAR 23-56	GOODYEAR 23-56S	GOODYEAR 23-56	GACO N-79	GACO N-79
OUTDOOR	1 YR.	1 YR.	1 YR.	1 YR.	1 YR.

B. RAIN EROSION OF COATINGS

TEST CONDITIONS:

AVERAGE SPEED: **500 M.P.H.**
ONE INCH PER HOUR RAIN FALL

0° ANGLE OF ATTACK
MEDIAN DROPLET SIZE 1.9 M M

NO EROSION.

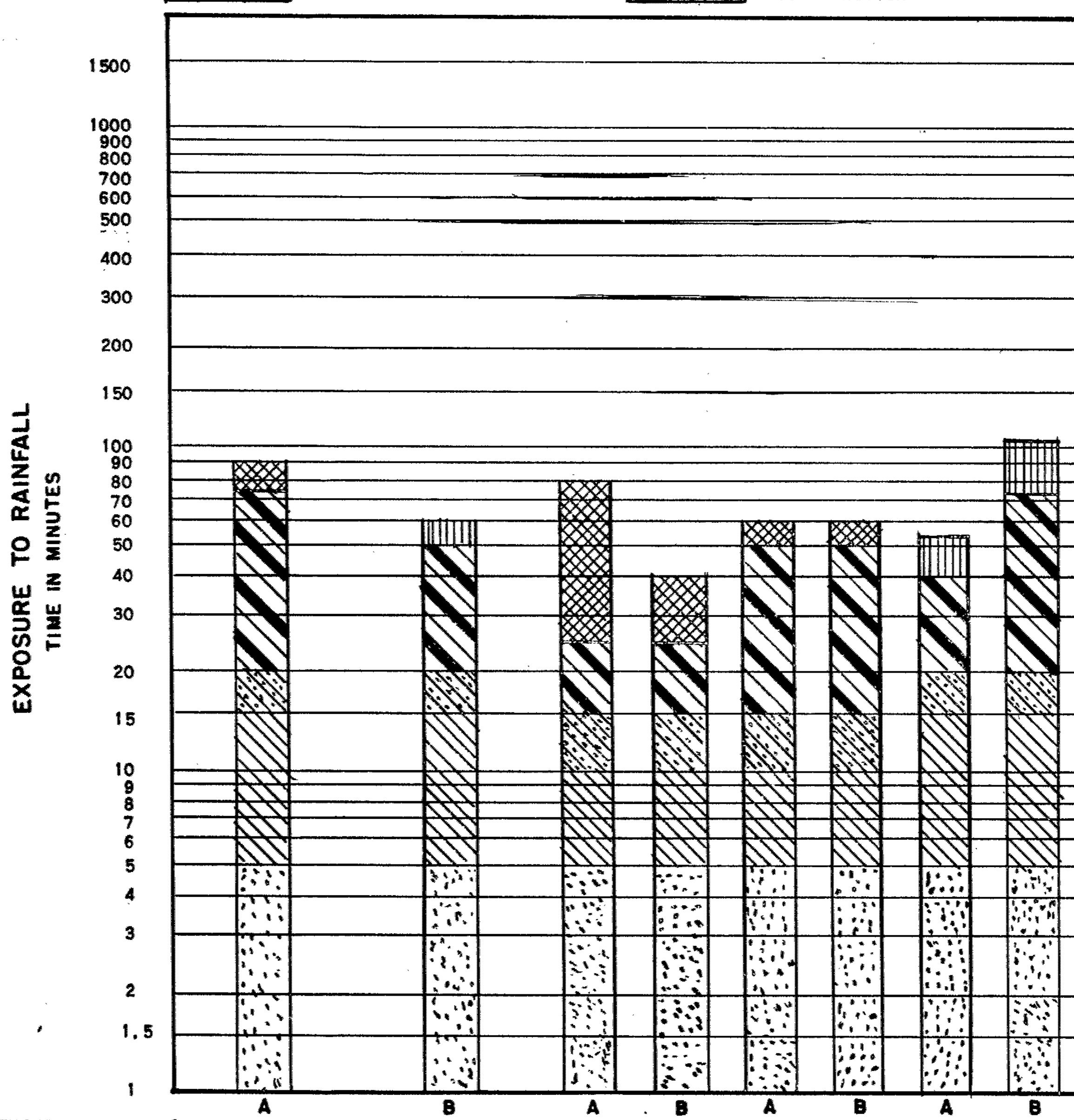
COATING ABRADED AT HIGH SPEED END

COATING PITTED ALONG LEADING EDGE

EROSION THRU COATING AT HIGH SPEED END

THRU COATING & FIRST PLY OF CLOTH

FAILURE POOR ADHESION



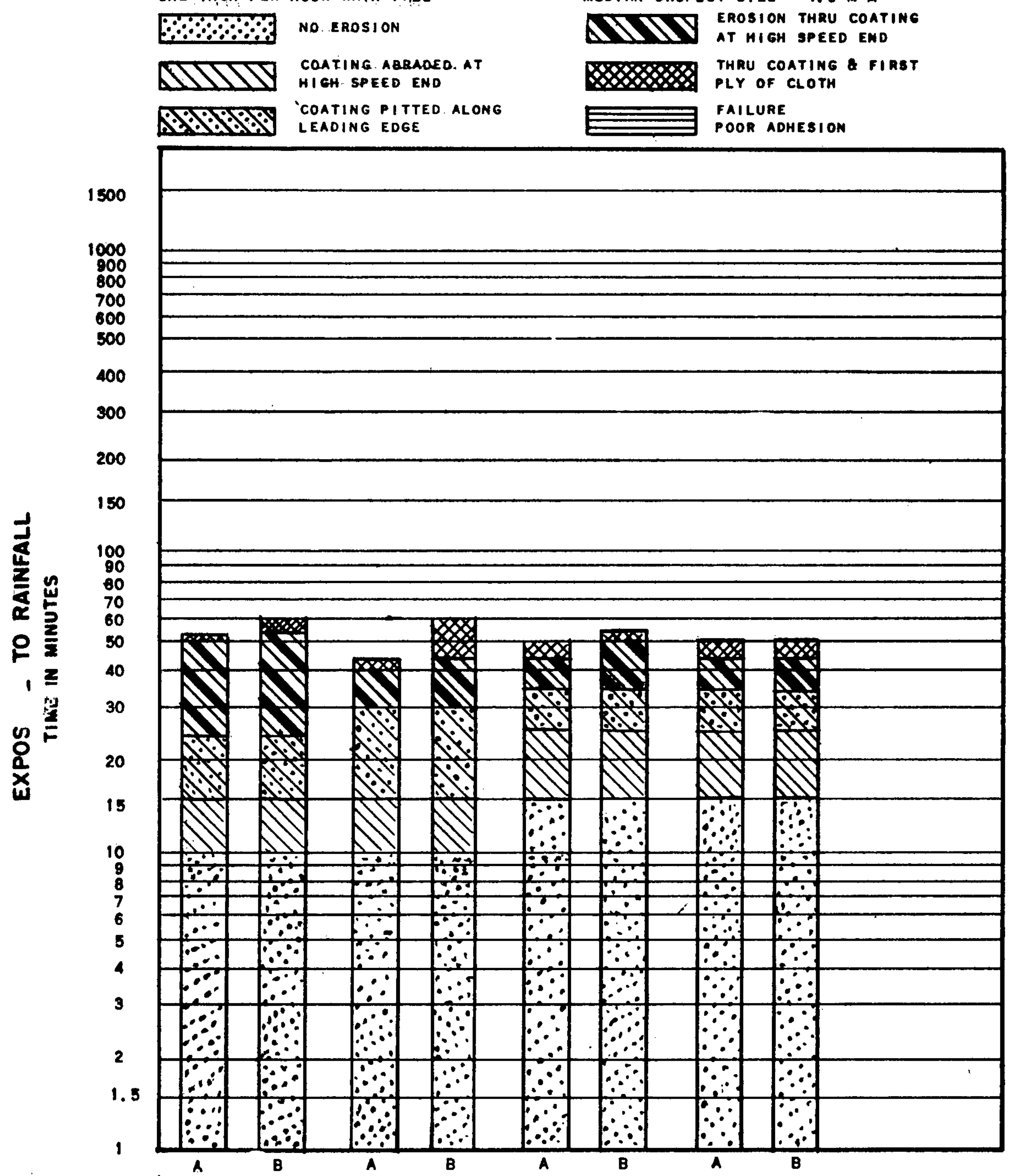
SPECIMEN NO.	416	420	535	551	554
PRIMER	BOSTIK 1007	BOSTIK 1007	BOSTIK 1007	BOSTIK 4764 - 27	BOSTIK 4764 - 27
TOP COAT	GOODYEAR 23-56 BRUSH	GOODYEAR 23-56 SPRAY	GACO N-79 BRUSH	GACO N-700-9 BRUSH	GOODYEAR 23-56 BRUSH
OUTDOOR EXPOSED	3 MO.	3 MO.	6 MO.	3 MO.	3 MO.

c. RAIN EROSION OF COATINGS

TEST CONDITIONS:

AVERAGE SPEED: 500 MPH
ONE INCH PER HOUR RAIN FALL

0° ANGLE OF ATTACK
MEDIAN DROPLET SIZE 1.9 MM



SPECIMEN NO.	664	665	669	670	
PRIMER	GACO N-15	"	"	"	
TOP COAT	GACO N-79	"	"	"	
CURING SCHEDULE	AIR DRY 150 HRS.	AIR DRY 150 HRS	BAKE 20 HRS. AT 200° F	BAKE 20 HRS. AT 200° F	

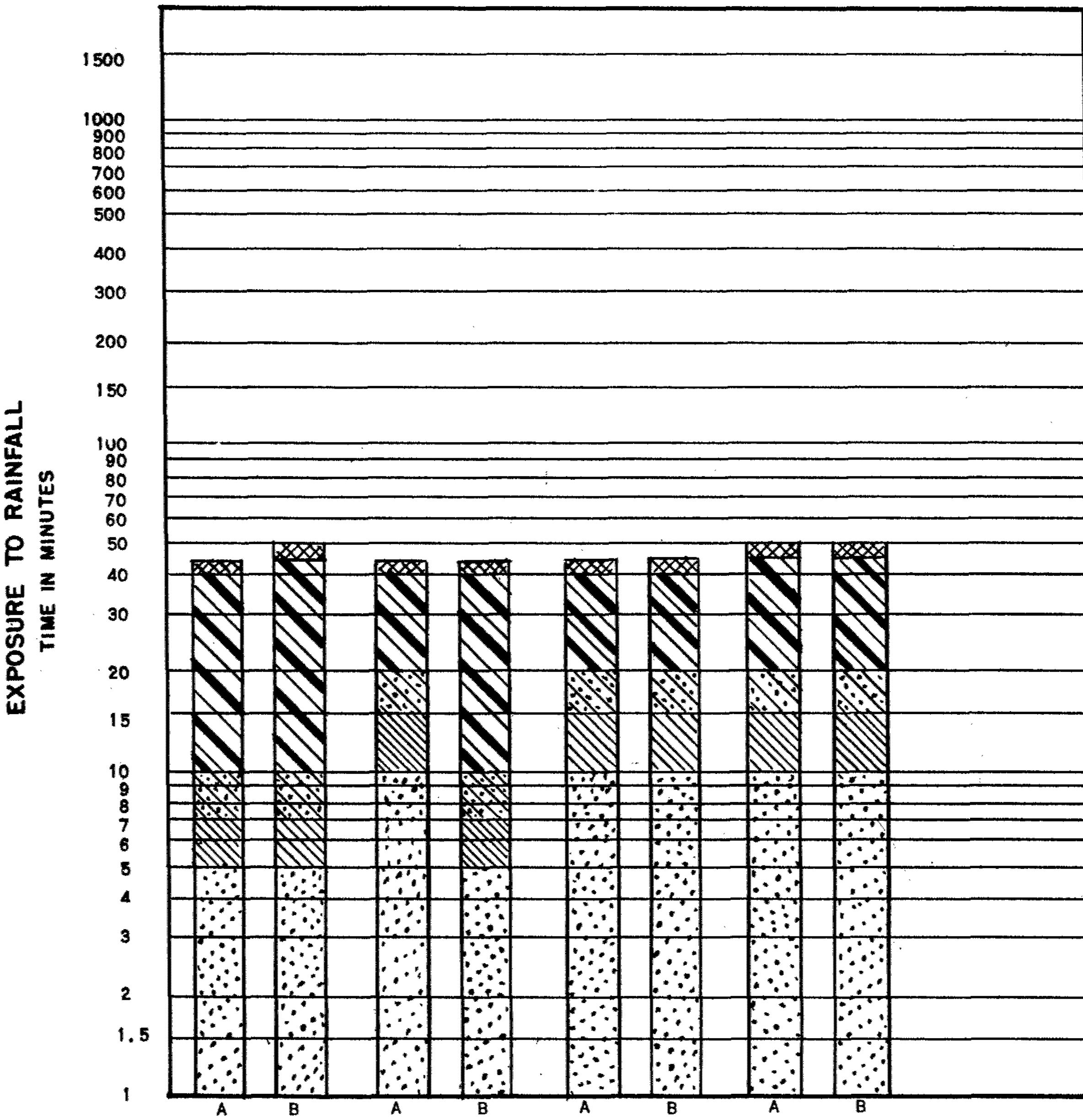
D. RAIN EROSION OF COATINGS

TEST CONDITIONS:

AVERAGE SPEED: 500 MPH
ONE INCH PER HOUR RAIN FALL

0° ANGLE OF ATTACK
MEDIAN DROPLET SIZE 1.9 M M

NO EROSION
COATING ABRADED AT HIGH SPEED END
COATING PITTED ALONG LEADING EDGE
EROSION THRU COATING AT HIGH SPEED END
THRU COATING & FIRST PLY OF CLOTH
FAILURE POOR ADHESION

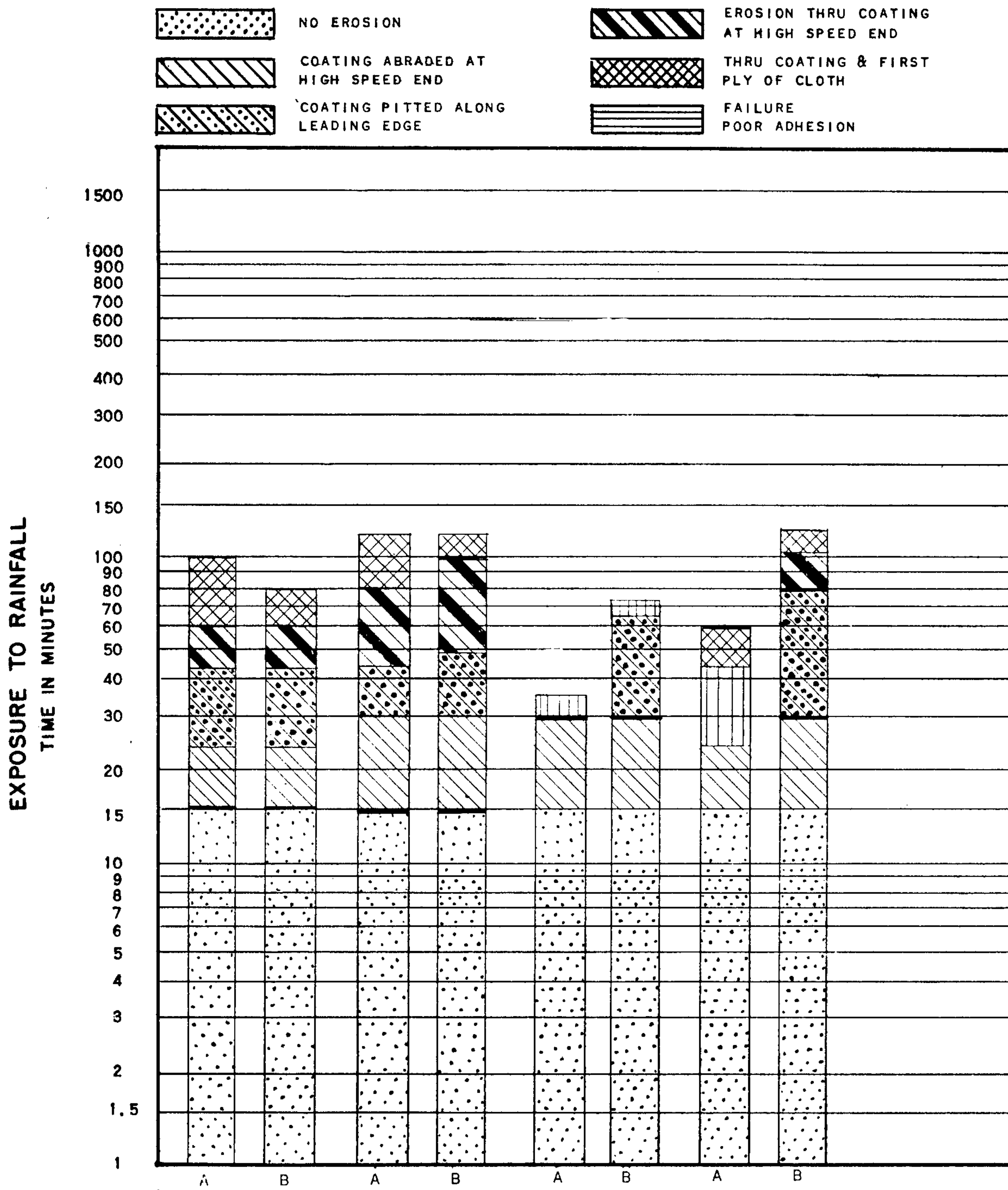


SPECIMEN NO.	671	672	676	680	
PRIMER	GACO N-15	"	"	"	
TOP COAT	GACO N-51	"	"	"	
CURING SCHEDULE	AIR DRY 150 HRS.	AIR DRY 150 HRS.	BAKE 20 HRS. AT 200° F	BAKE 20 HRS. AT 200° F	

E. RAIN EROSION OF COATINGS

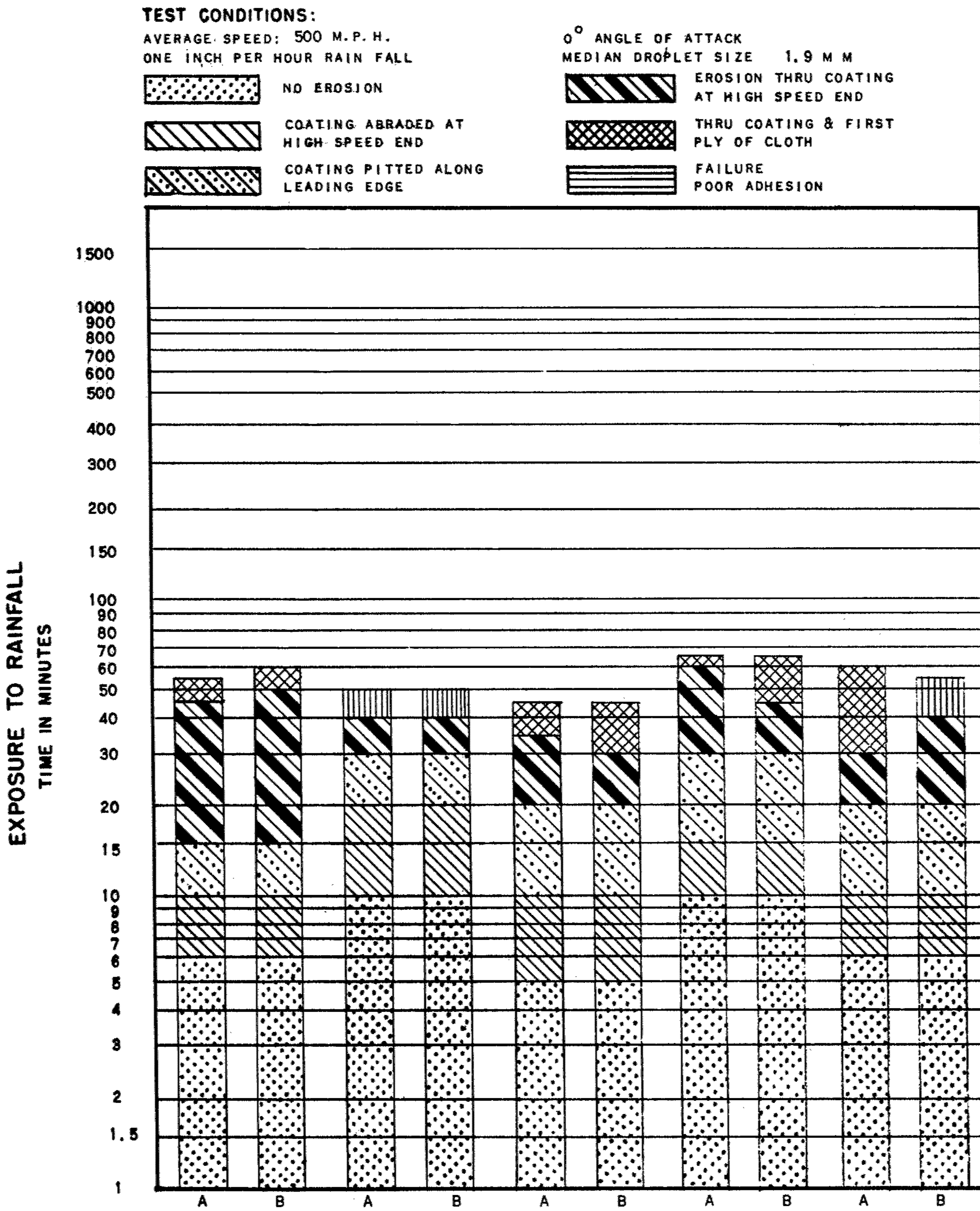
TEST CONDITIONS:

AVERAGE SPEED: 500 M.P.H.
ONE INCH PER HOUR RAIN FALL
0° ANGLE OF ATTACK
MEDIAN DROPLET SIZE 1.9 MM



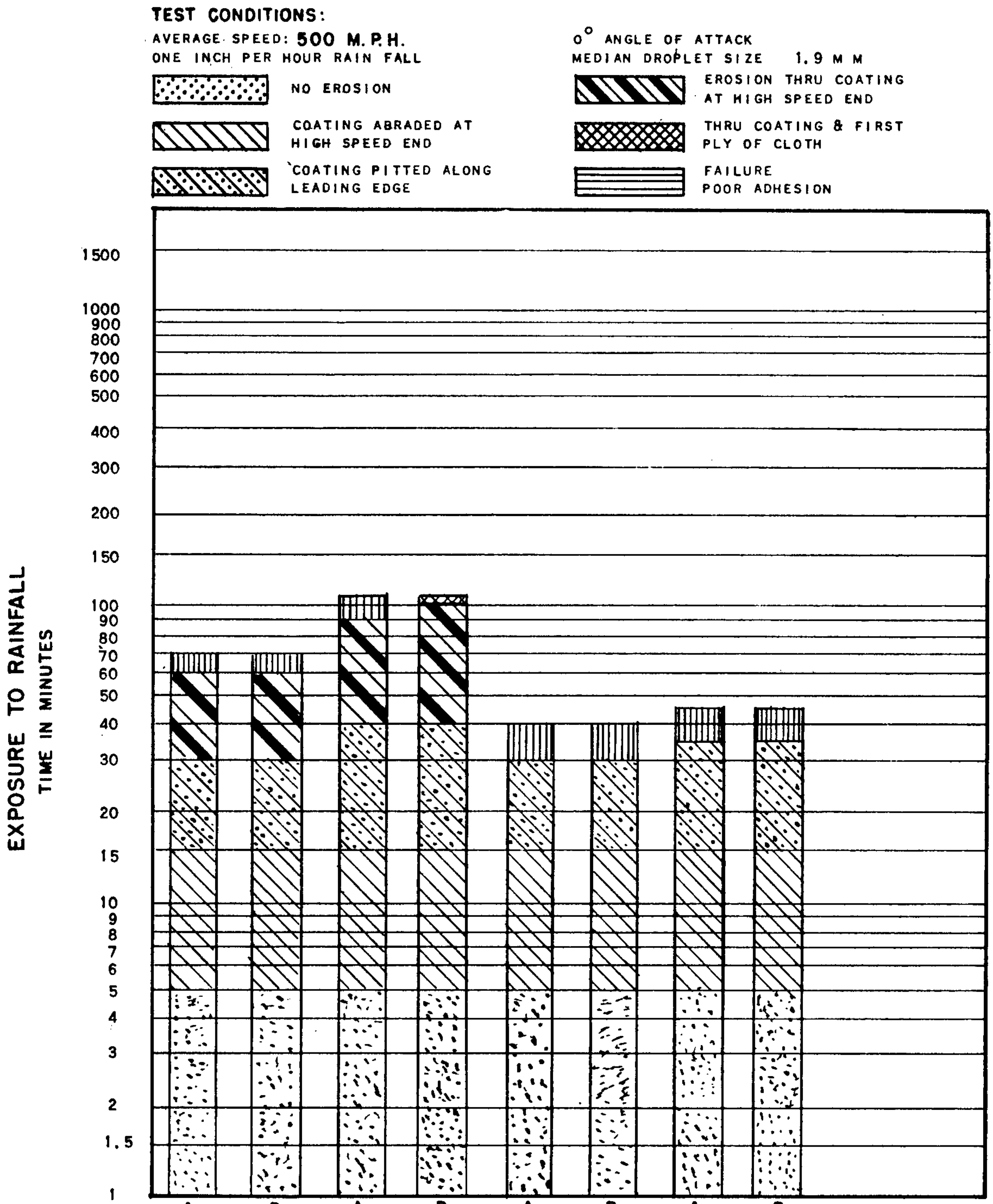
SPECIMEN NO.	643	644	645	646	
PRIMER	BOSTIK 4764-90	BOSTIK 4764-90	PRO SEAL 581	PRO-SEAL 581	
TOP COAT	GACO N-79	GOODYEAR 23 56	GACO N-79	GOODYEAR 23-56	

F. RAIN EROSION OF COATINGS



SPECIMEN NO.	556	652	653	654	655
PRIMER	BOSTIK 4764-27	GACO N-15	GACO N-15	THIXON G 135	THIXON G 135
TOP COAT	GOODYEAR 23-56	GOODYEAR 23-56	GACO N-79	GOODYEAR 23-56	GACO N-79
OUTDOOR EXPOSED	1 YR.	3 MO.	3 MO.	3 MO.	3 MO.

G. RAIN EROSION OF COATINGS



SPECIMEN NO.	591	599	593	594	
PRIMER	GACO N-15	GACO N-15	3M-EC 579	3M EC-579	
TOP COAT	GACO N-79	GOODYEAR 23-56	GACO N-79	GOODYEAR 23-56	
COATING THICKNESS (MILS)	10 MIL	11 MIL	9 MIL	9 MIL	

H. RAIN EROSION OF COATINGS

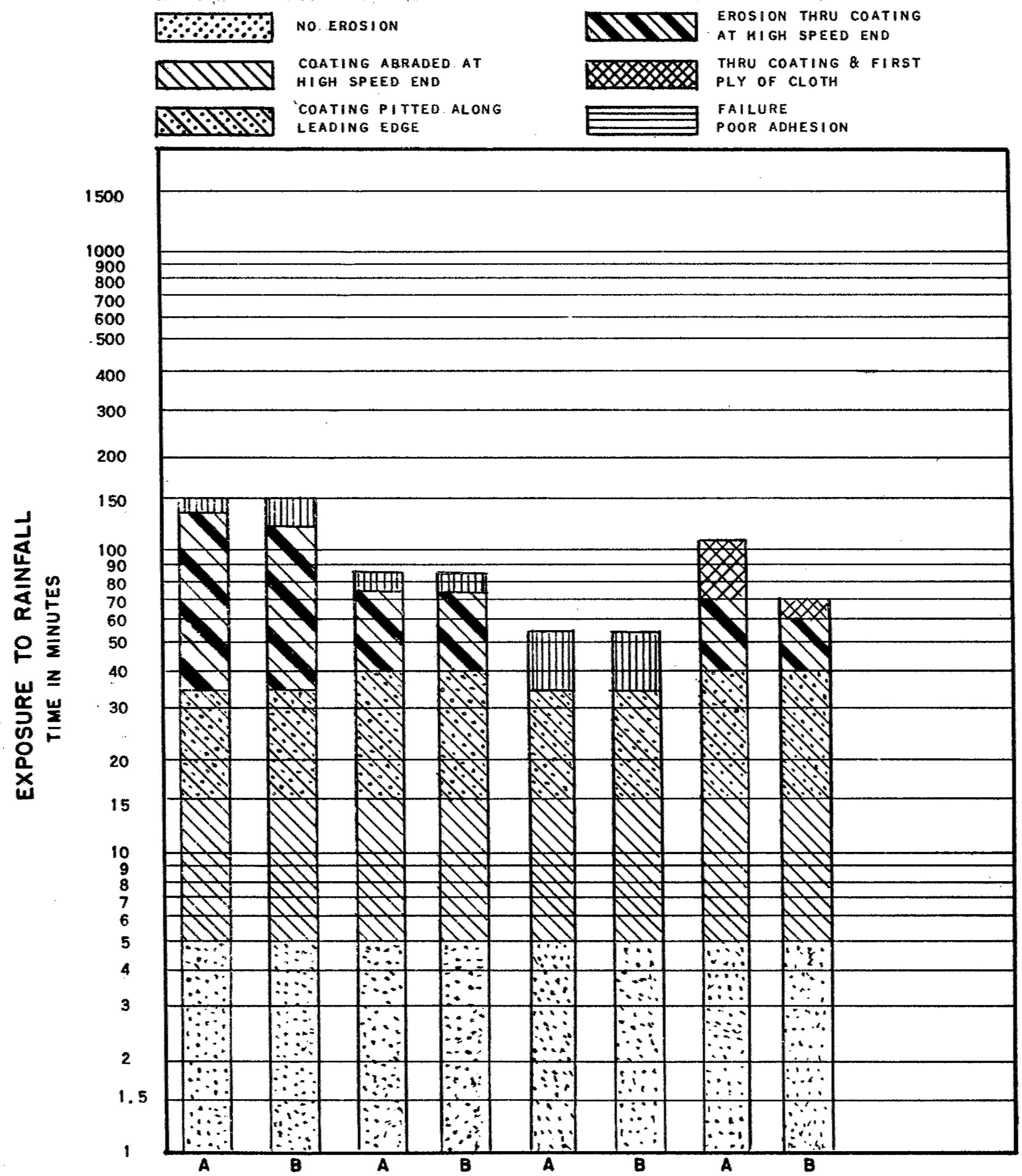
TEST CONDITIONS:

AVERAGE SPEED: 500 M.P.H

ONE INCH PER HOUR RAIN FALL

0° ANGLE OF ATTACK

MEDIAN DROPLET SIZE 1.9 M M



SPECIMEN NO.	595	596	597	598	
PRIMER	PLIOBOND	PLIOBOND	HYSOL 6109	HYSOL 6109	
TOP COAT	GACO N-79	GOODYEAR 23-56	GACO N-79	GOODYEAR 23-56	
COATING THICKNESS (MILS	12 MIL	11 MIL	12 MIL	10 MIL	

I. RAIN EROSION OF COATINGS

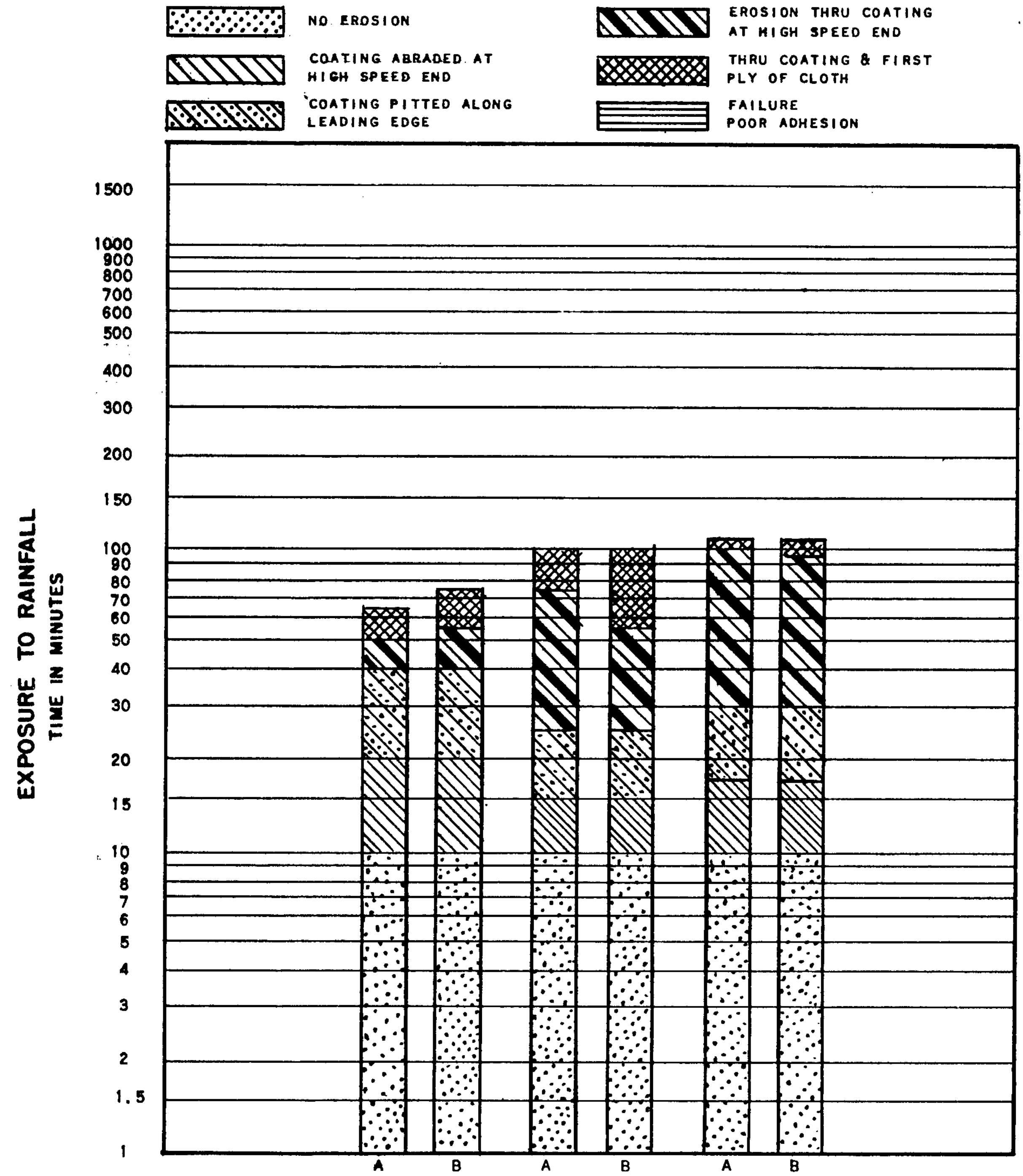
TEST CONDITIONS:

AVERAGE SPEED: 500 MPH

ONE INCH PER HOUR RAIN FALL

0° ANGLE OF ATTACK

MEDIAN DROPLET SIZE 1.9 MM

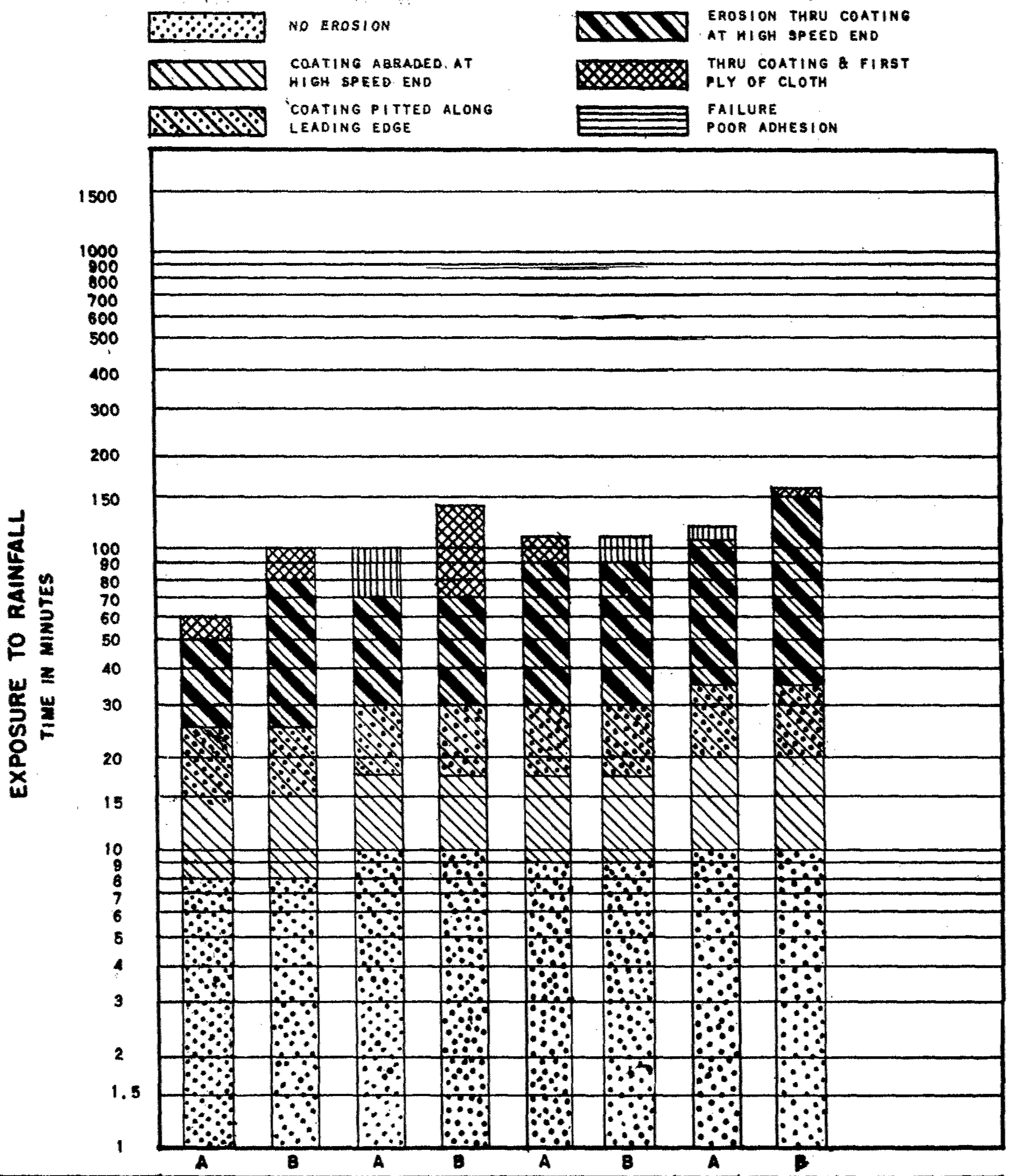


SPECIMEN NO.		681	682	683	
PRIMER		BOSTIK 1007	BOSTIK 1007	BOSTIK 1007	
TOP COAT		GOODYEAR R14L-23-370	GOODYEAR R14L-23-371	GOODYEAR R14L-23-372	
COATED BY		GOODYEAR	AIRCRAFT	SPECIMENS	

J. RAIN EROSION OF COATINGS

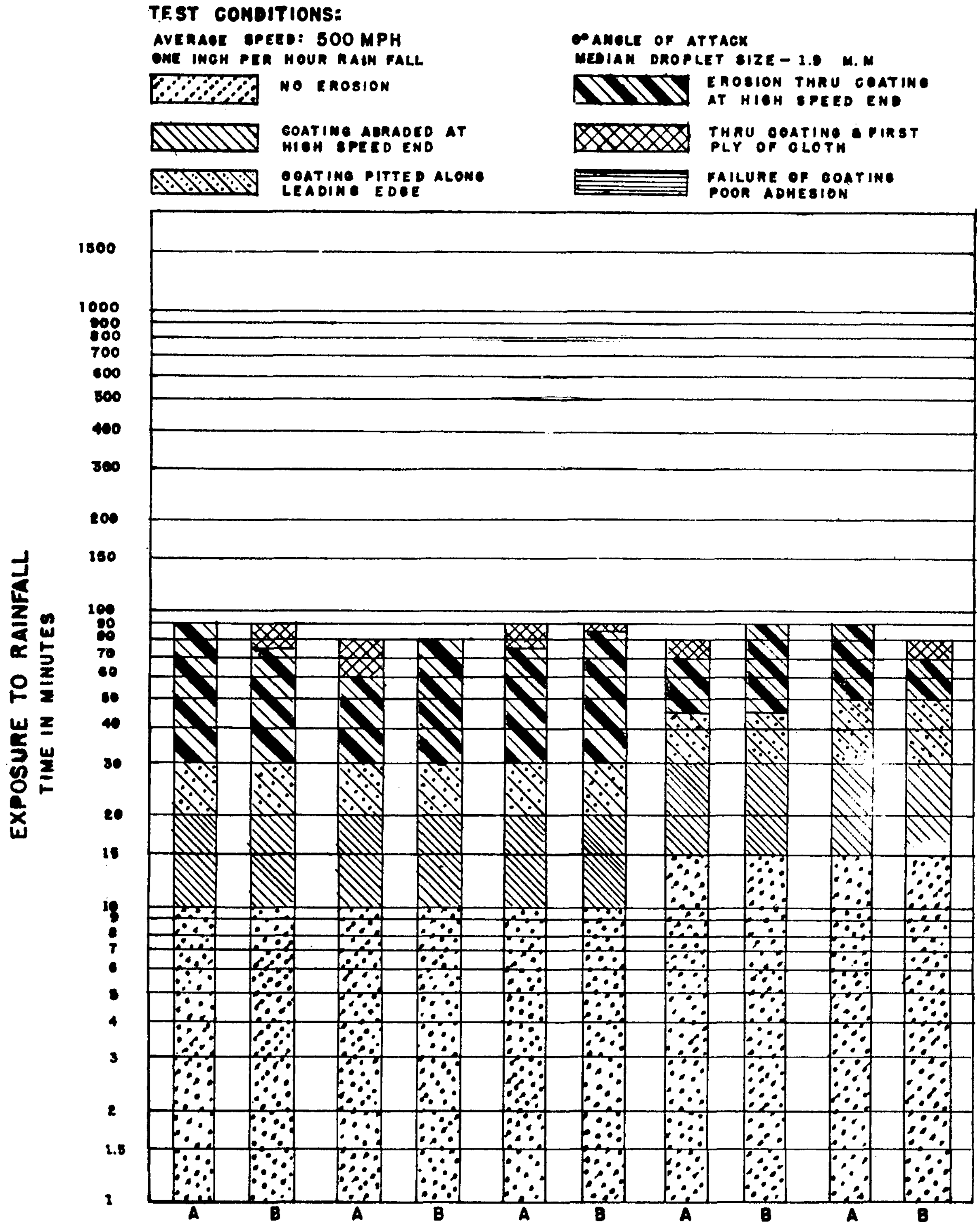
TEST CONDITIONS:

AVERAGE SPEED: 500 M.P.H.
ONE INCH PER HOUR RAIN FALL
0° ANGLE OF ATTACK
MEDIAN DROPLET SIZE 1.9 M M



SPECIMEN NO.	601	602	611	612	
PRIMER	THIXON EXP. G135	THIXON EXP. G135	BOSTIK 1007	BOSTIK 1007	
TOP COAT	GOODYEAR 23-56	GACO N-79	GOODEAR 23-56	GACO N-79	
CURING SCHEDULE	AIR DRIED 200 HRS.	AIR DRIED 200 HRS.	AIR DRIED FOR 300 HRS. L.E. IMMERSED IN DEICING SOLUTION 24 HRS.		

K. RAIN EROSION OF COATINGS



SPECIMEN NO.	539	540	541	547	548
	BOSTIK 4764-27	S *	S *	S *	S *
TOP COAT	GACO N-79	S *	S *	S *	S *
	AIR DRY 200 HRS	S *	S *	BAKE 20 HRS. 200° F	BAKE 20 HRS. 200° F

* – Same as previous coatings

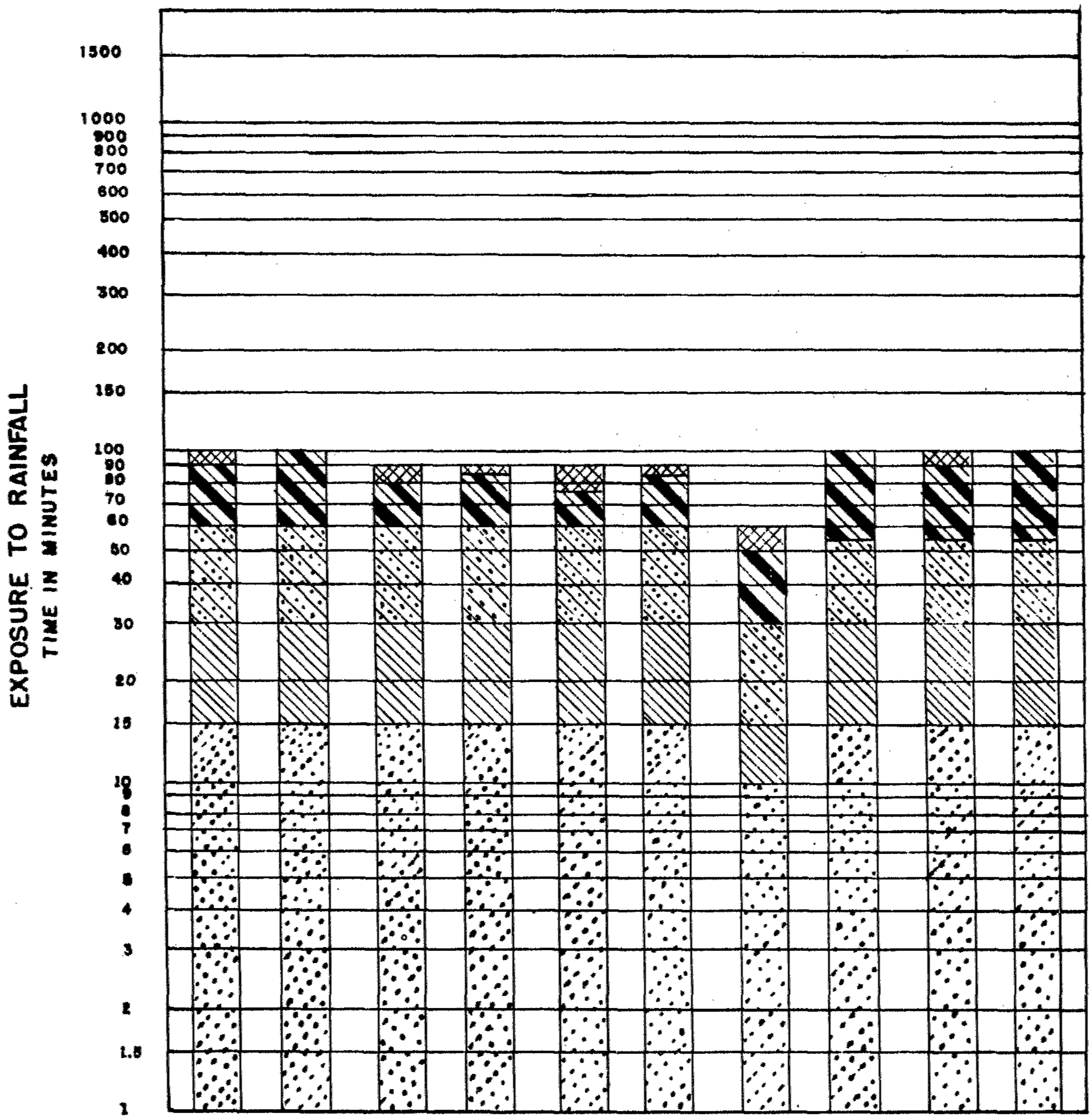
D. RAIN EROSION OF COATINGS

TEST CONDITIONS:

AVERAGE SPEED: 500 MPH
ONE INCH PER HOUR RAIN FALL

0° ANGLE OF ATTACK
MEDIAN DROPLET SIZE – 1.9 M.M

- NO EROSION
- COATING ABRADED AT HIGH SPEED END
- COATING PITTED ALONG LEADING EDGE
- EROSION THRU COATING AT HIGH SPEED END
- THRU COATING & FIRST PLY OF CLOTH
- FAILURE OF COATING POOR ADHESION



SPECIMEN NO.	542	543	544	545	546
	BOSTIK 4764-27	S*	S*	S*	S*
TOP COAT	GOODYEAR 23-56	S*	S*	S*	S*
	AIR DRY 200 HRS.	S*	S*	BAKE 20 HRS. 200° F	S*

* – Same as previous coatings

M. RAIN EROSION OF COATINGS

TEST CONDITIONS:

AVERAGE SPEED: 500 MPH
ONE INCH PER HOUR RAIN FALL

0° ANGLE OF ATTACK
MEDIAN DROPLET SIZE 1.9 M M

NO EROSION

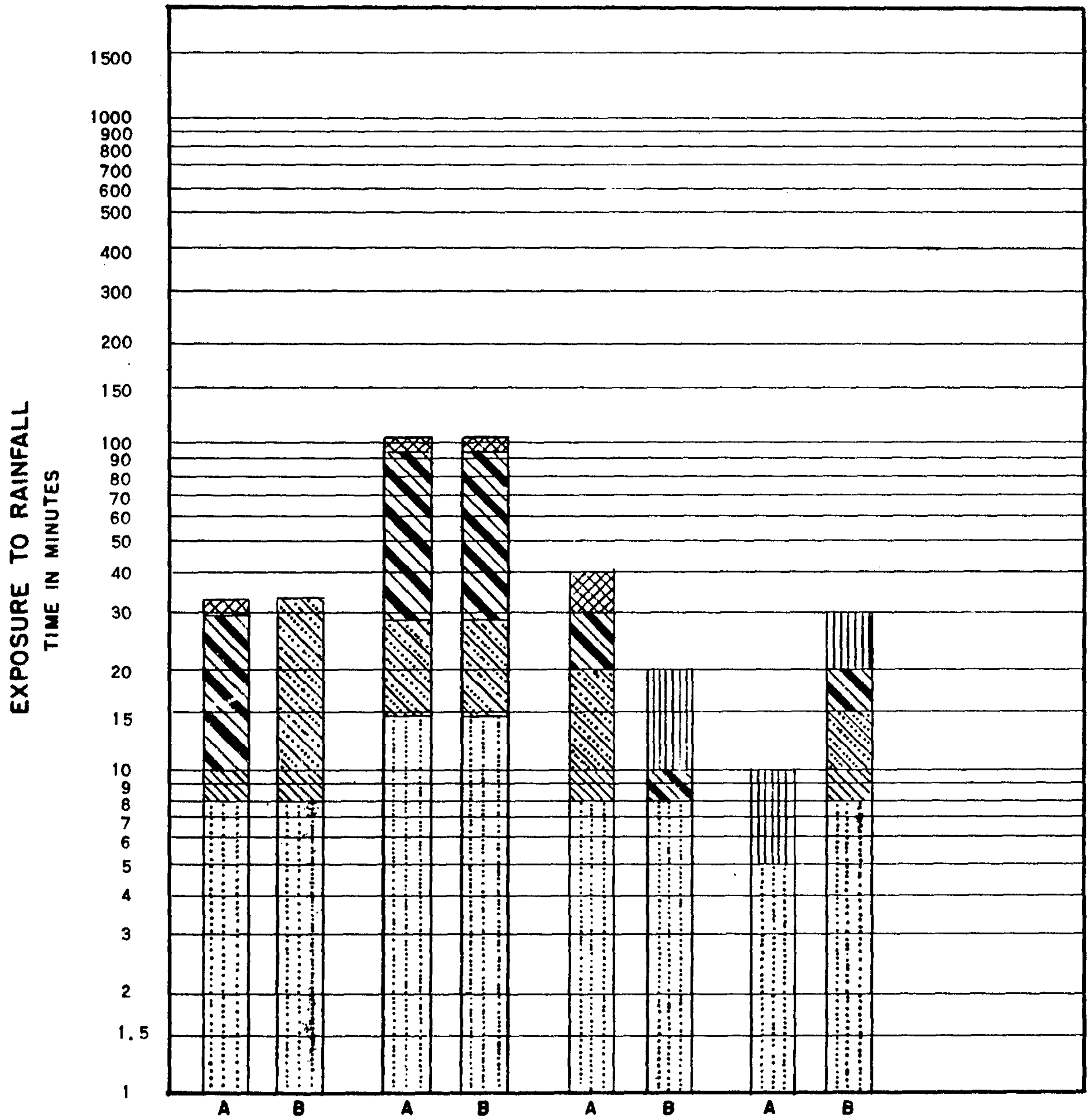
COATING ABRADED AT HIGH SPEED END

COATING PITTED ALONG LEADING EDGE

EROSION THRU COATING AT HIGH SPEED END

THRU COATING & FIRST PLY OF CLOTH

FAILURE POOR ADHESION



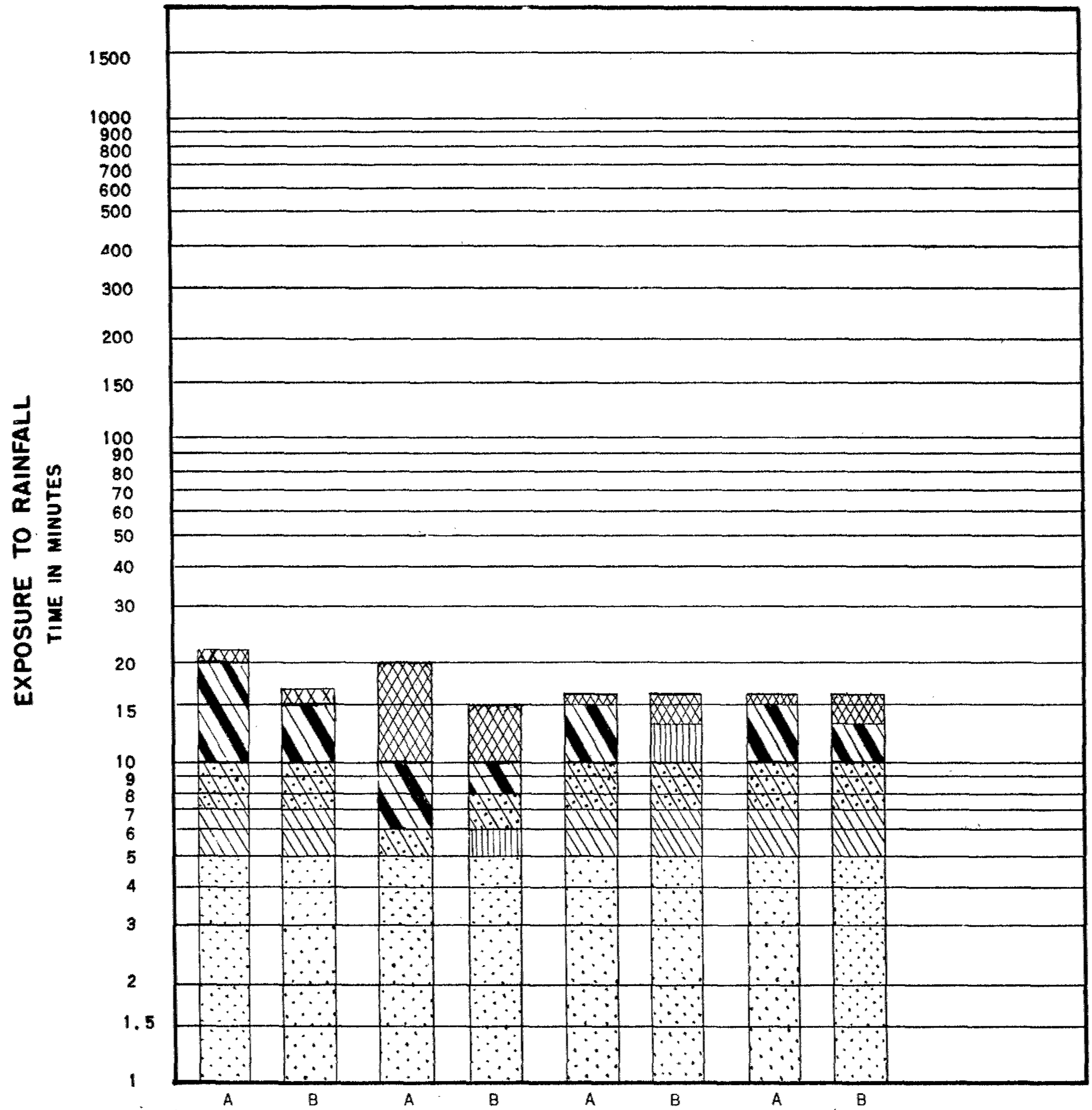
SPECIMEN NO.	558	560	576	579	
PRIMER	BOSTIK 4764 27	BOSTIK 4764 27	BOSTIK 1007	BOSTIK 1007	
TOP COAT	GACO N 79	GOODYEAR 23 56	GACO N-79	GOODYEAR 23-56	
DRYING SCHEDULE	AIR DRY — 400 HRS; BAKE {4 HRS AT 175°F, 10 MIN AT 400°F}		AIR DRY — 100 HRS; BAKE {4 HR 175°F, 10 MIN 400°F}		

N. RAIN EROSION OF COATINGS

TEST CONDITIONS:

AVERAGE SPEED: 500 MPH
ONE INCH PER HOUR RAIN FALL
0° ANGLE OF ATTACK
MEDIAN DROPLET SIZE 1.9 M M

- NO EROSION
- COATING ABRADED AT HIGH SPEED END
- COATING PITTED ALONG LEADING EDGE
- EROSION THRU COATING AT HIGH SPEED END
- THRU COATING & FIRST PLY OF CLOTH
- FAILURE POOR ADHESION

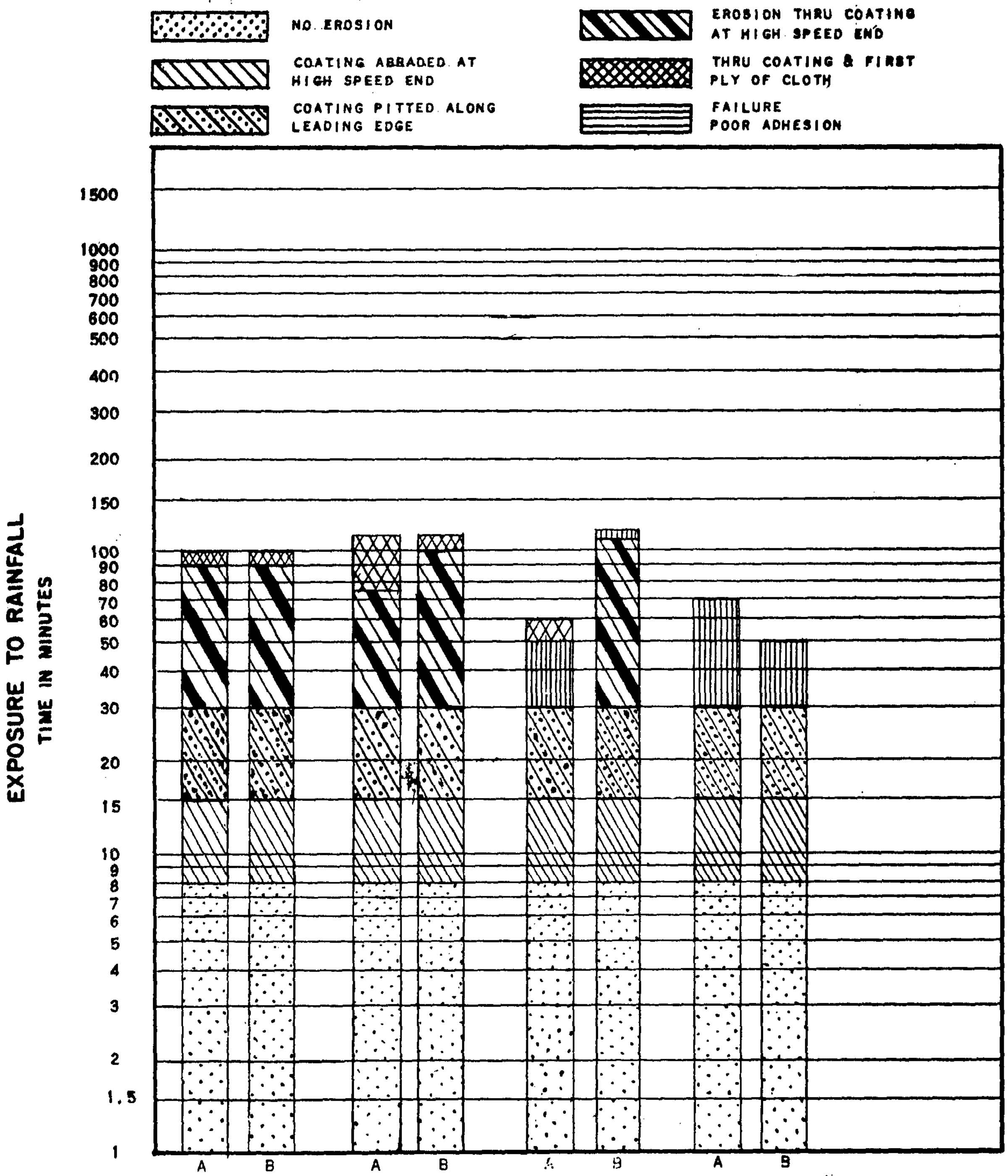


SPECIMEN NO.	634	635	636	637	
PRIMER	BOSTIK 1007	BOSTIK 1007	BOSTIK 1007	BOSTIK 1007	
TOP COAT	GOODYEAR R14L-27-86	GOODYEAR R14L-27-86	GOODYEAR R14L-27-86	GOODYEAR R14L-27-86	
COATED BY	GOODYEAR	GOODYEAR	C.A.L	C.A.L	

o. RAIN EROSION OF COATINGS

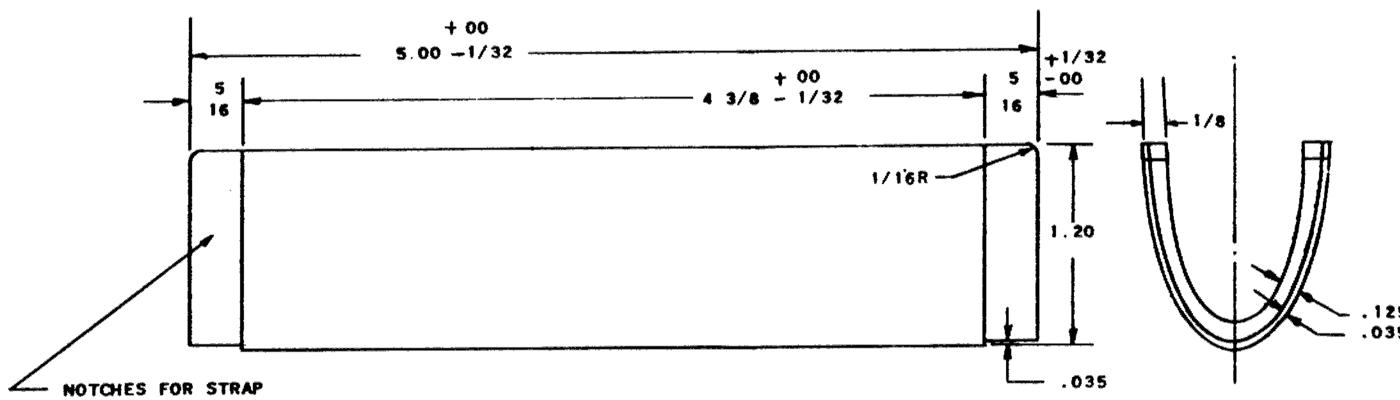
TEST CONDITIONS:

AVERAGE SPEED: 500 MPH
ONE INCH PER HOUR RAIN FALL
0° ANGLE OF ATTACK
MEDIAN DROPLET SIZE 1.9 M M



SPECIMEN NO.	614	615	616	617	
PRIMER	PLIOBOND	PLIOBOND	GOODYEAR M 450 C	GOODYEAR M 450 C	
TOP COAT	GOODYEAR 23-56	GOODYEAR 23-56	GOODYEAR 23-56	GOODYEAR 23-56	

RAIN EROSION TEST SPECIMEN



.0025 AIRFOIL - 4" CHORD

% CHORD	ORDINATES DISTANCE FROM L.E.	ORDINATE
.00	.00	.00
1.25	.05	.158
2.50	.10	.218
5.00	.20	.296
7.50	.30	.350
10.00	.40	.390
16.00	.60	.446
20.00	.80	.478
25.00	1.00	.485
30.00	1.20	.500

OUTER DIMENSIONS OF 1/8" SPECIMEN

Section II
Figure 1 Rain Erosion Test Specimen

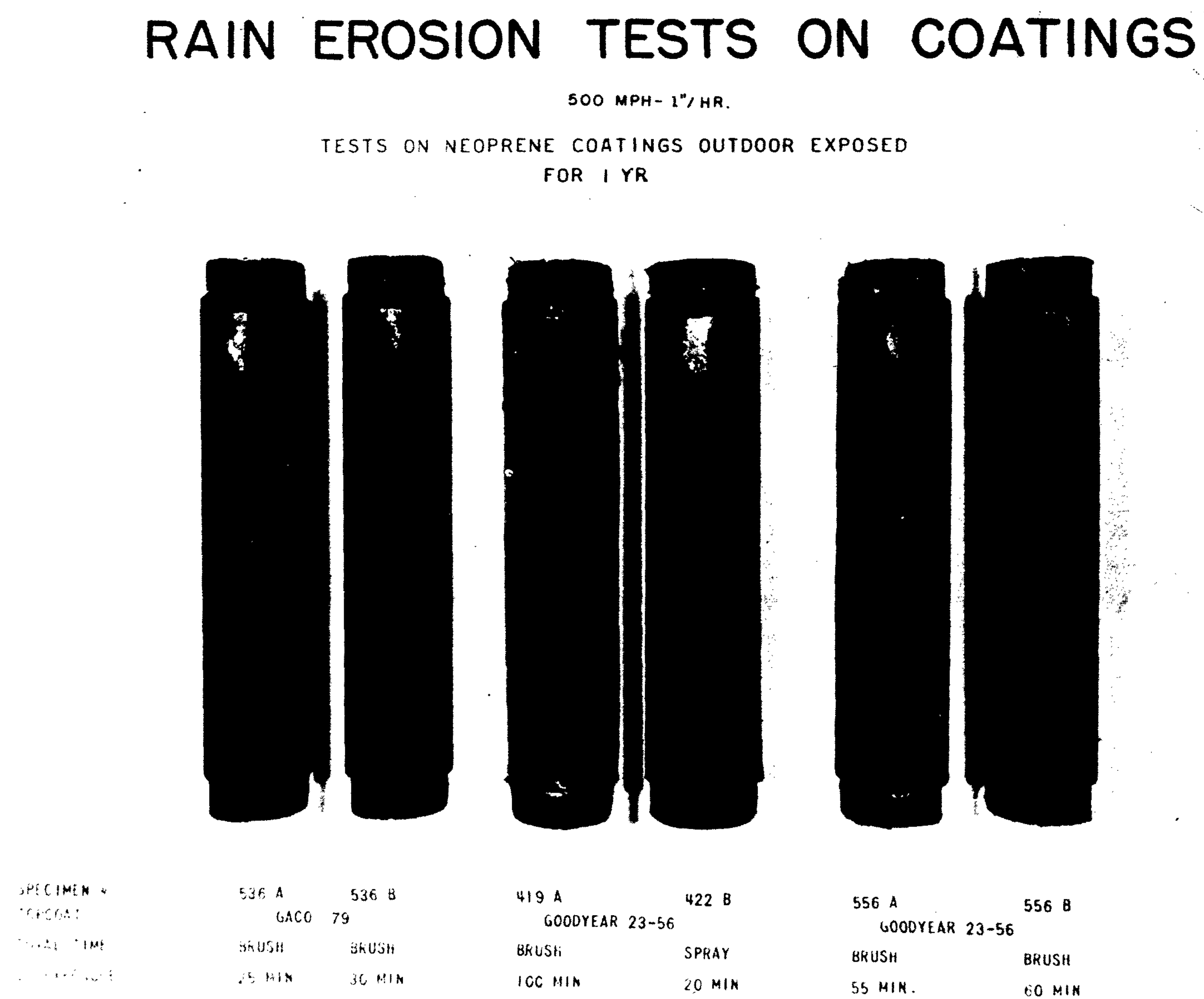


Figure 2 View of Neoprene Coatings After One Year's Outdoor Exposure

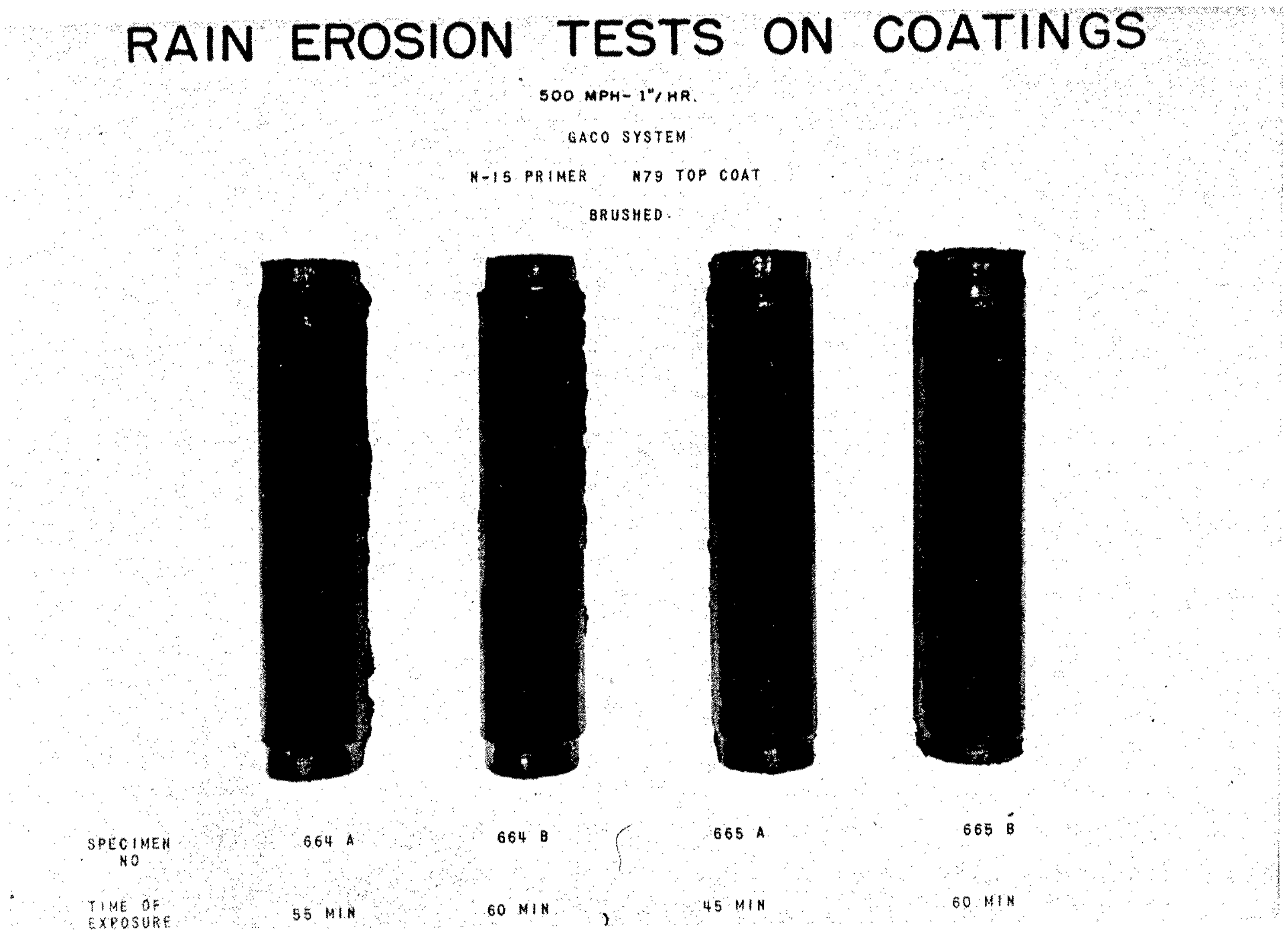


Figure 3 Gaco N-79 Specimens After Test

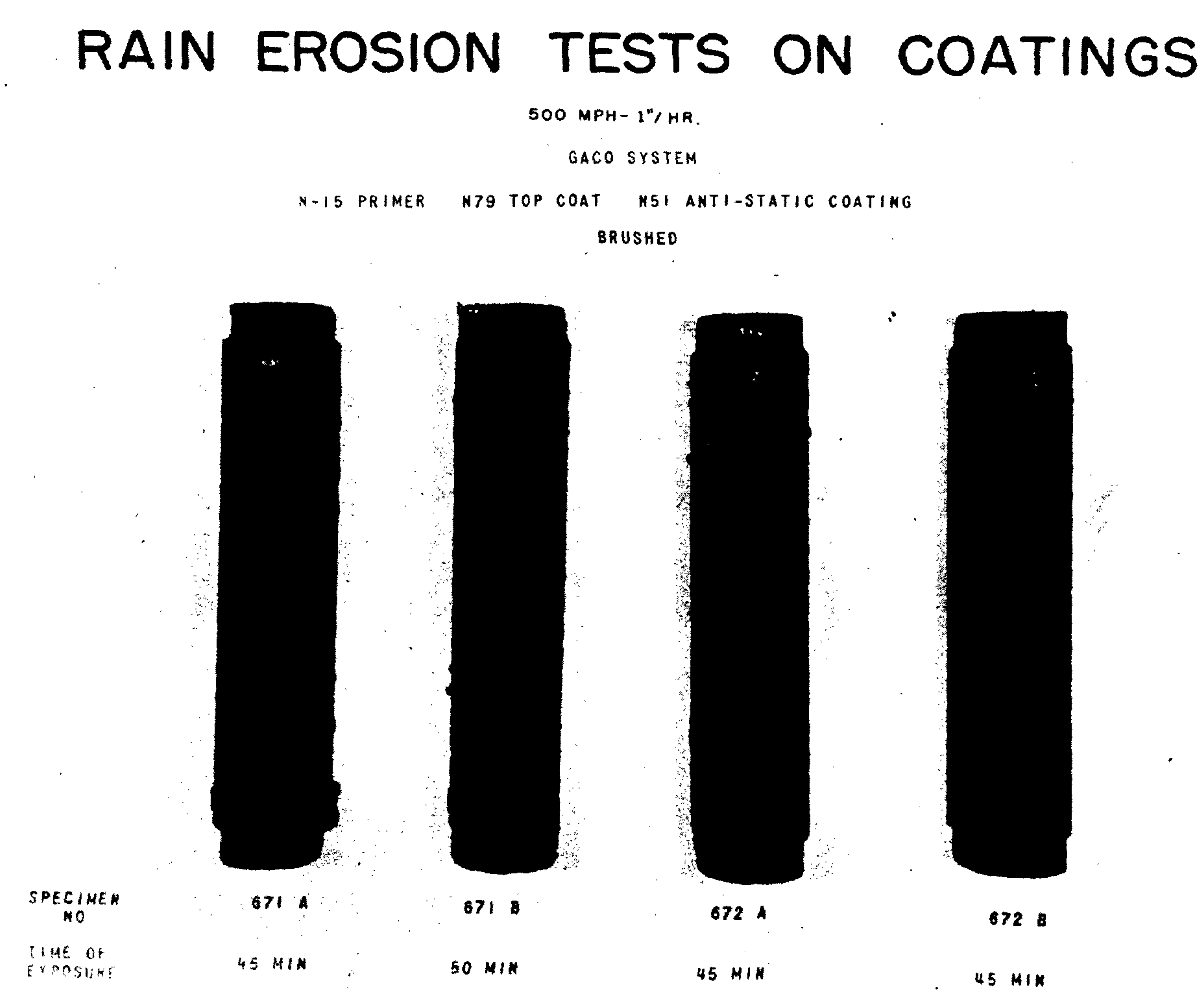
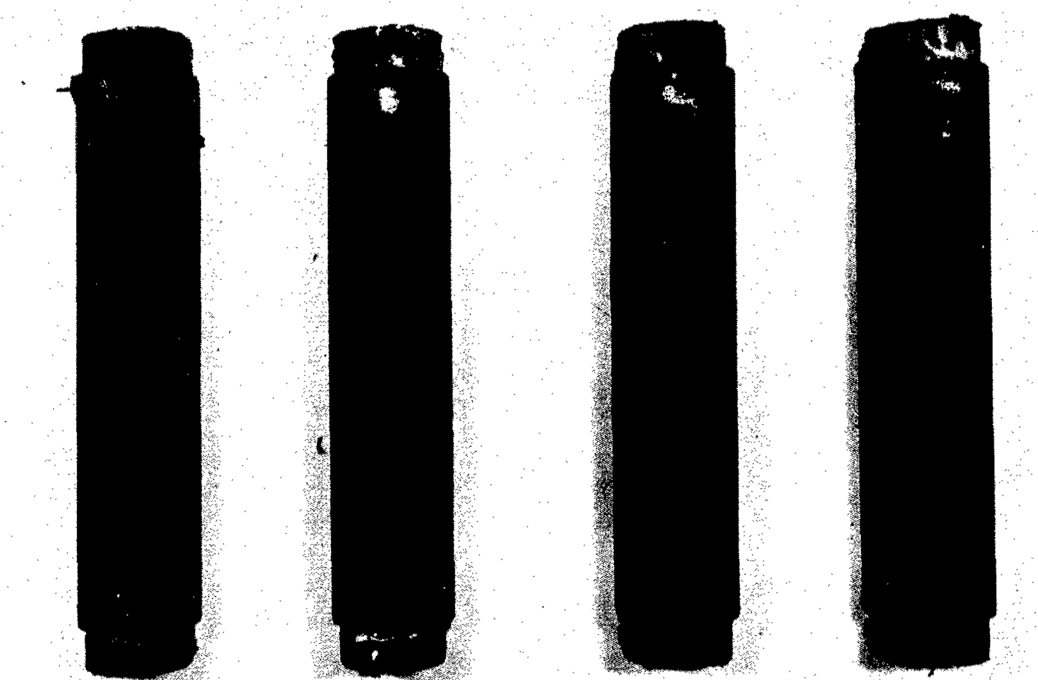


Figure 4 Gaco Anti-static Specimens After Evaluation

RAIN EROSION TESTS ON COATINGS

500 MPH-1"/HR.

TEST ON NEOPRENE COATINGS AFTER SIX MONTHS OUTDOOR EXPOSURE



SPECIMEN NO.	552 A	552 B	555 A	555 B
[illegible]	BOSTIK 4764-27	BOSTIK 4764-27	BOSTIK 4764-27	BOSTIK 4764-27
[illegible]	GACO N-79	GACO N-79	GOODYEAR 23-56	GOODYEAR 23-56
[illegible]	40 MIN.	50 MIN.	60 MIN.	80 MIN.

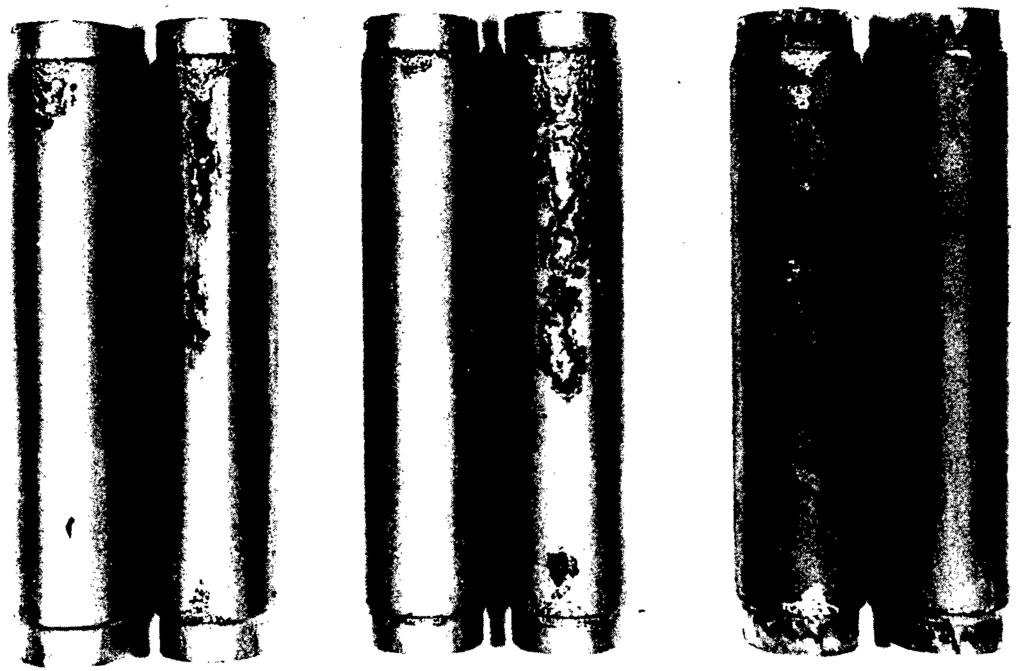
Figure 5 Rain Erosion Tests on Pro-Seal 581 primer

RAIN EROSION TESTS ON COATINGS

500 MPH- 1"/HR.

MINNESOTA MINING & MANUFACTURING COMPANY'S NEOPRENE COATINGS

ON FIBERGLAS SPECIMENS



SPEC #	366 A&B	367 A&B	368 A&B
TOPCOAT	3M-X33030	3M-X231108	3M-X34932-C
TIME OF EXPOSURE	6 MIN	5 MIN.	9 MIN.

Figure 6 View of 3M Coatings on Fiberglas After Test

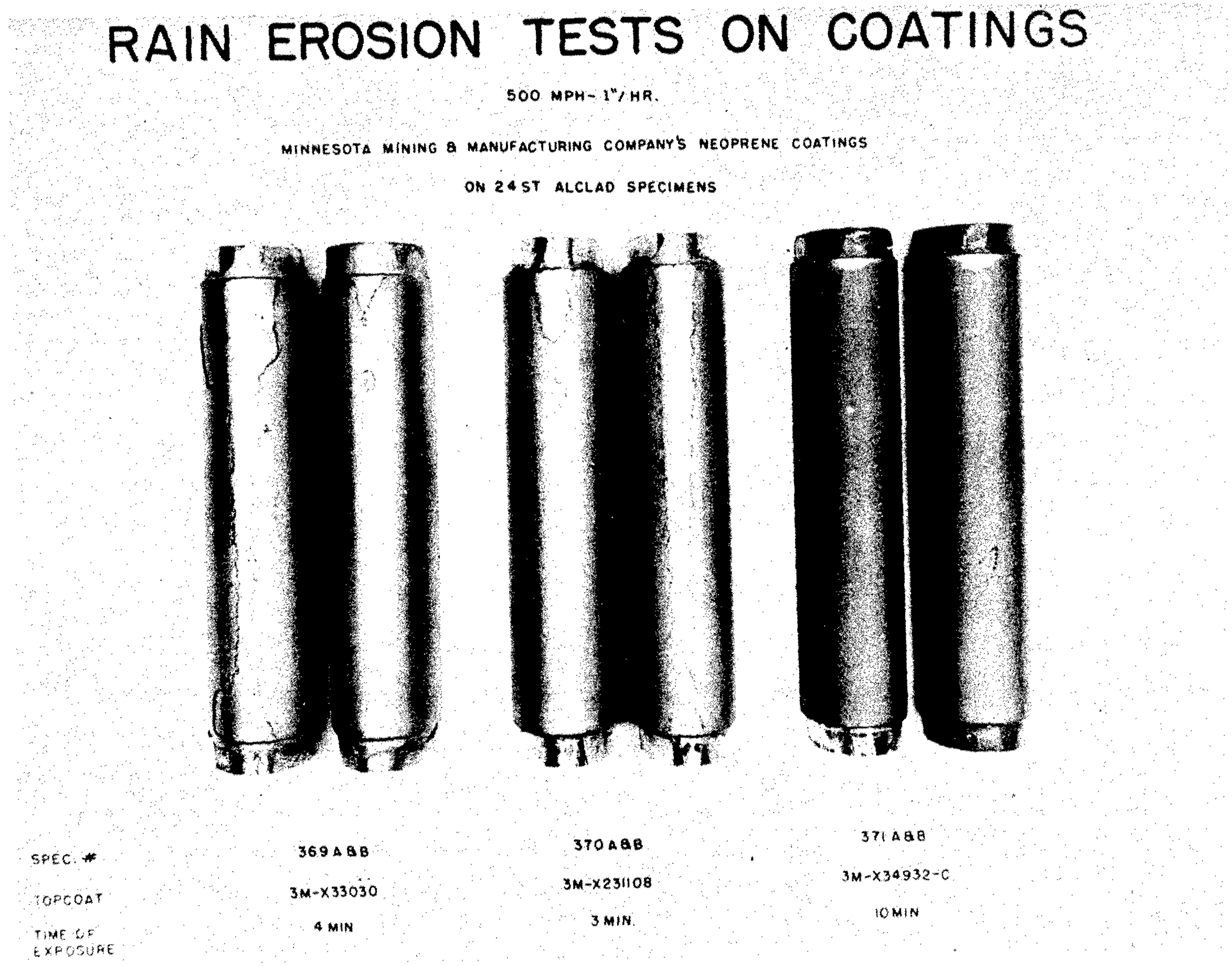


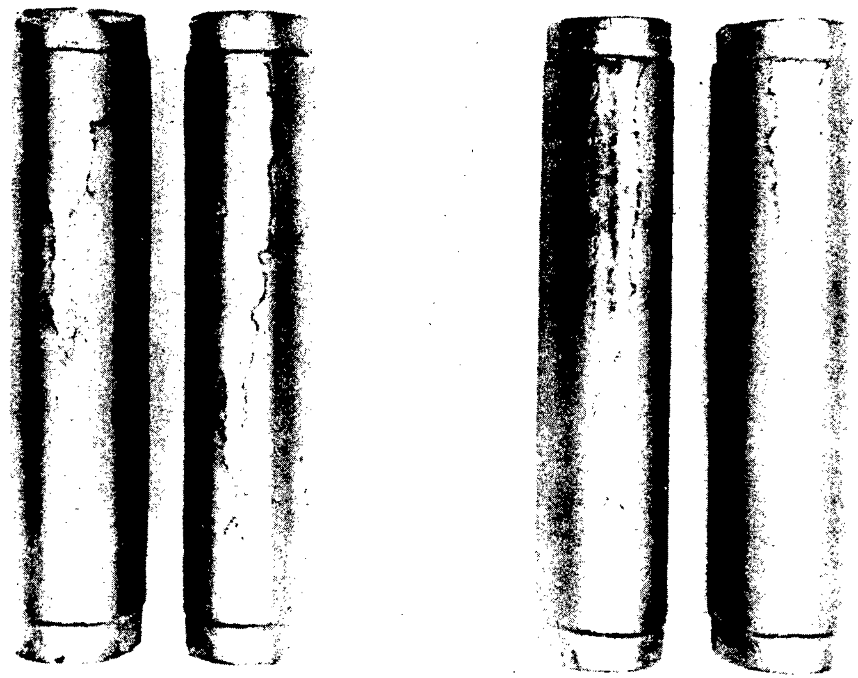
Figure 7 View of 3M Coatings on 24ST Alclad After Test

RAIN EROSION TESTS ON COATINGS

500 MPH - 1"/HR.

MINNESOTA MINING & MANUFACTURING COMPANY'S NEOPRENE COATINGS

ON FS1H MAGNESIUM SPECIMENS



SPEC #	372 A&B	373 A&B
TOPCOAT	3M-X33030	3M-X231108
TIME OF EXPOSURE	5 MIN.	3 MIN

Figure 8 View of 3M Coatings on FS1H Magnesium After Test

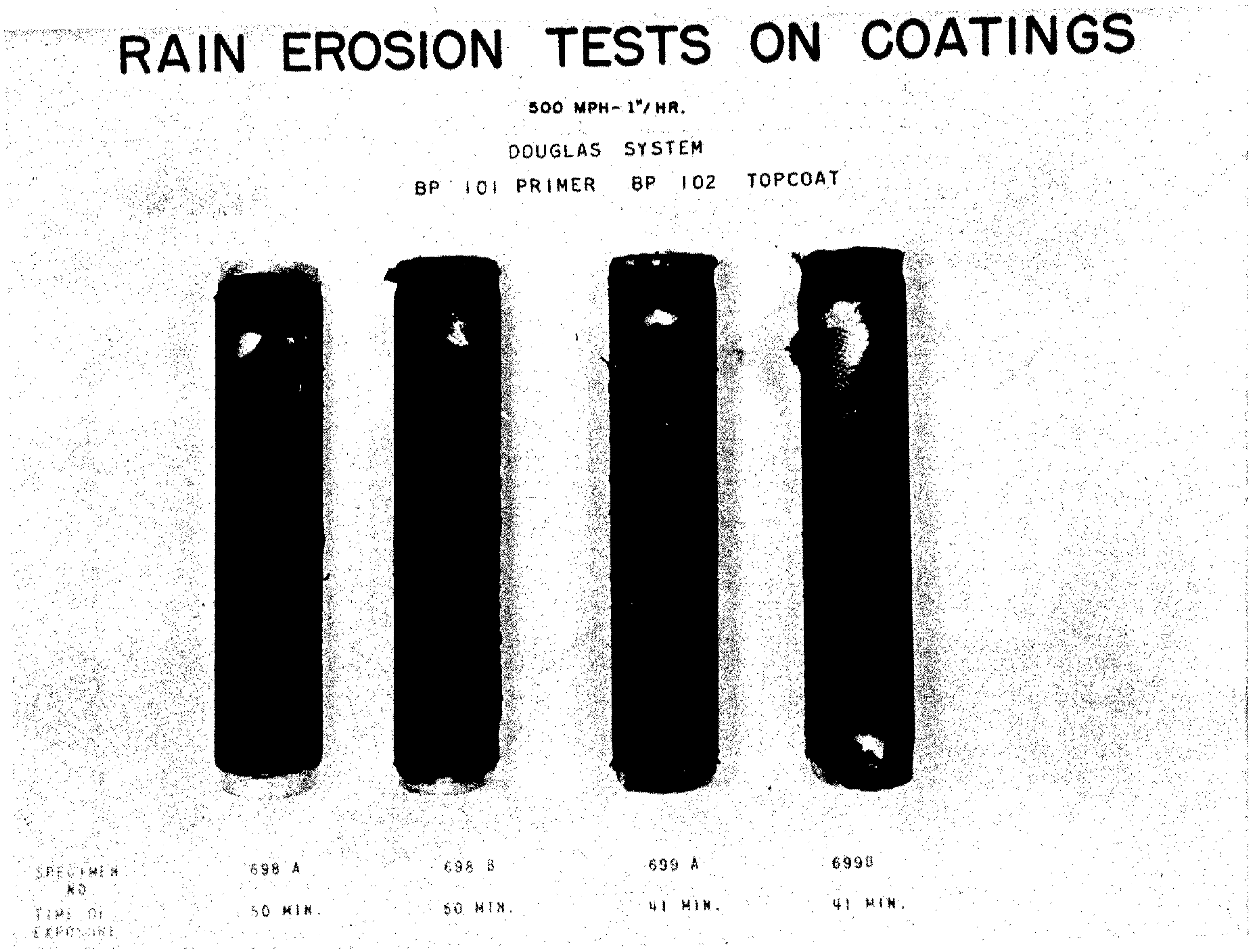
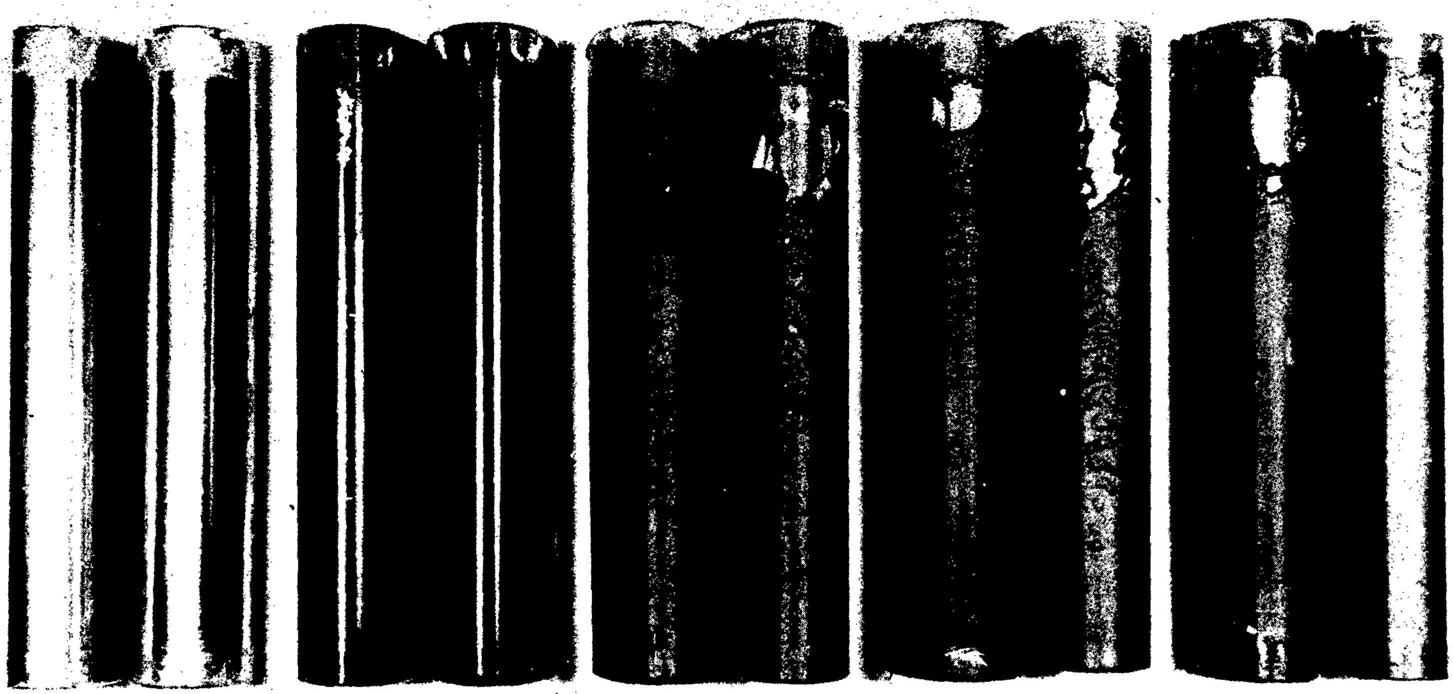


Figure 9 View of Douglas Coatings After Test

RAIN EROSION TESTS ON COATINGS

500 MPH- 1"/HR.



PIASECKI HELICOPTER CORPORATION SPECIMENS

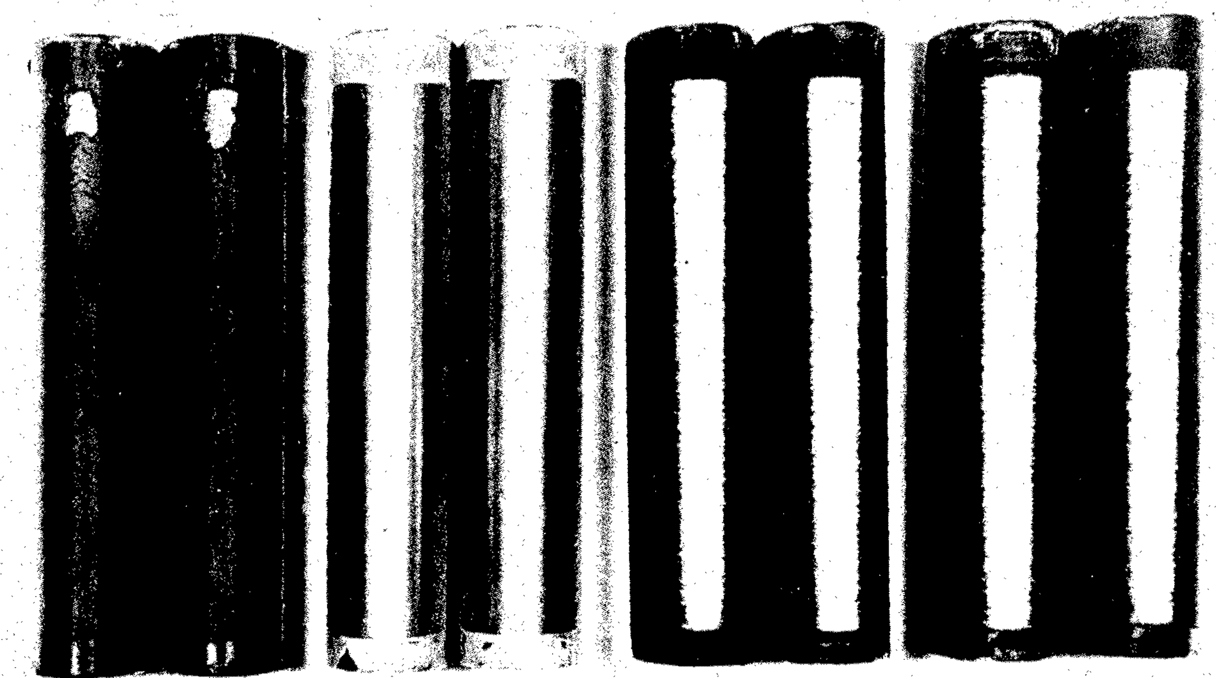
C.A.L. SPECIMEN NUMBER	620 A&B	621 A&B	622 A&B	623 A&B	624 A&B
PIASECKI CODE #	A-1 & A-2	B-1 & B-2	C-1 & C-2	D-1 & D-2	E-1 & E-2
TOTAL TIME OF EXPOSURE	130 MIN.	160 MIN.	16 MIN.	10 MIN. 12 MIN.	25 MIN. 30 MIN.

Figure 10 View of 4130 Steel Specimens With Various Finishes, After Test

RESTRICTED
MX-1925A

RAIN EROSION TESTS ON COATINGS

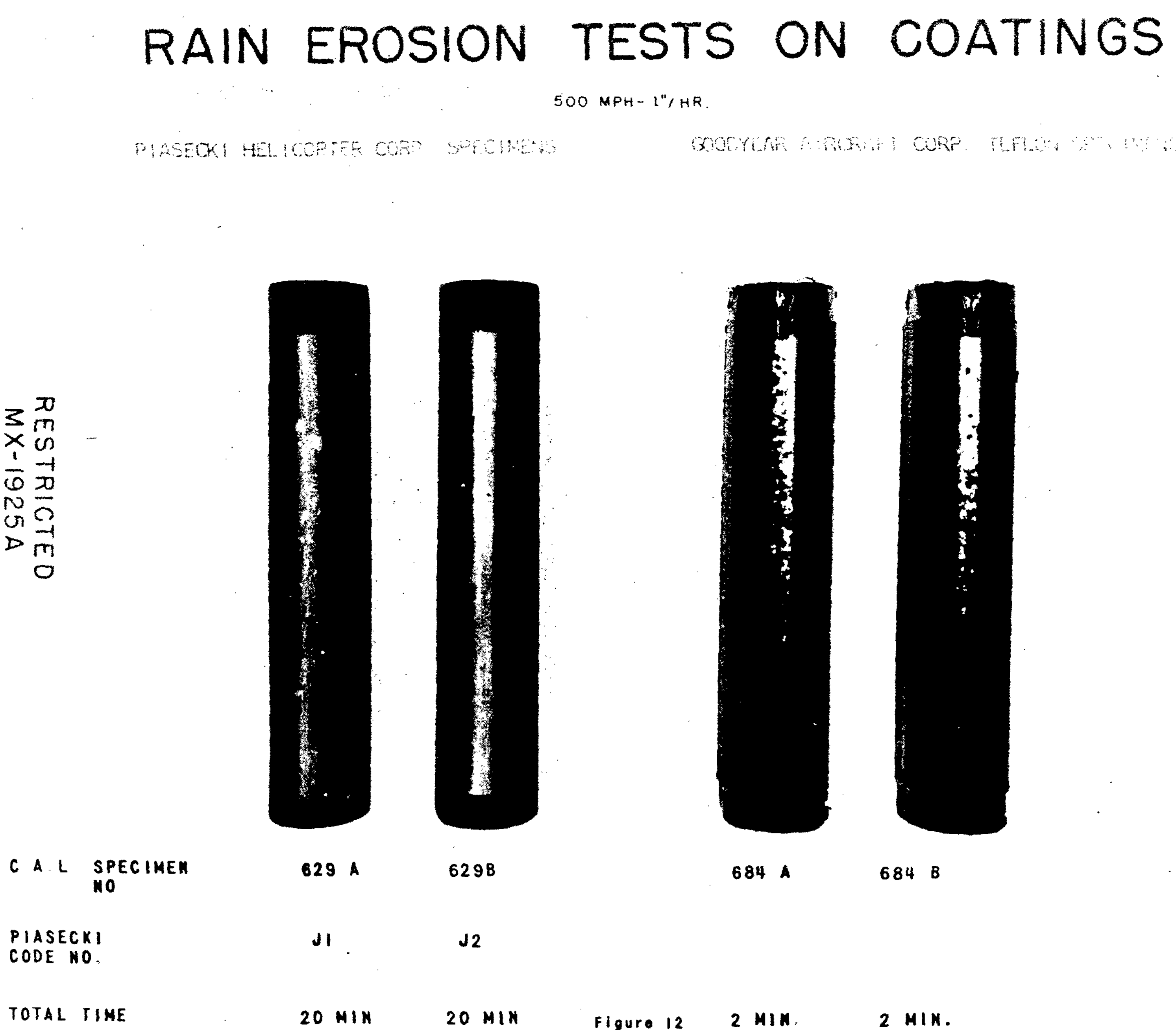
500 MPH- 1"/HR.



PIASECKI HELICOPTER CORPORATION SPECIMENS

C.A.L. SPECIMEN NUMBER	625 A&B	626 A&B	627 A&B	628 A&B
PIASECKI CODE NUMBER	F-1 & F-2	G-1 & G-2	H-1 & H-2	I-1 & I-2
TOTAL TIME OF EXPOSURE	31 MIN. 28 MIN.	600 MIN.	2 MIN.	2 MIN.

Figure 11 View of 4130 Steel Specimens With Various Finishes, After Test



RESTRICTED
MX-1925A

Figure 12 View of Piasecki and Goodyear Specimens, After Testing

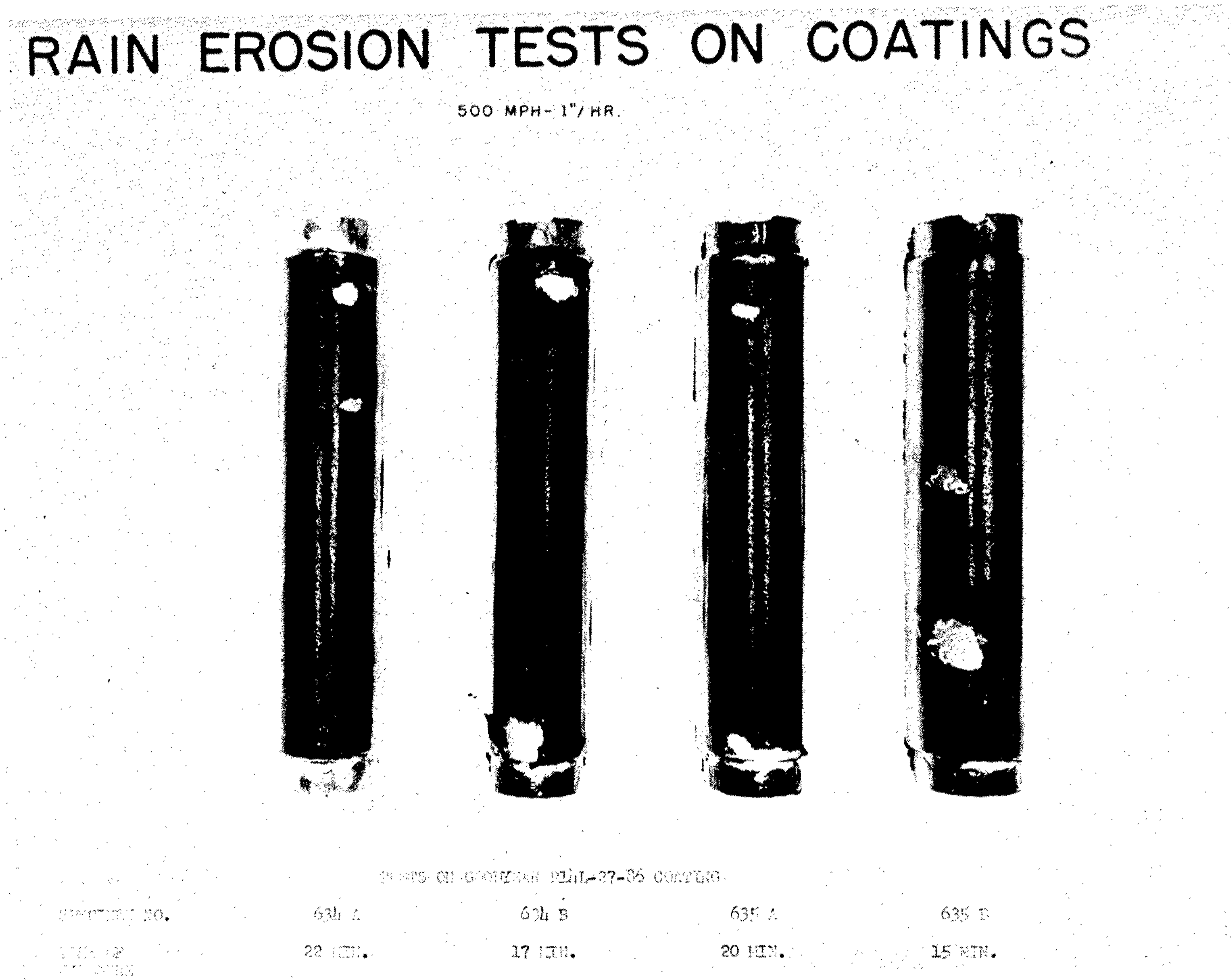
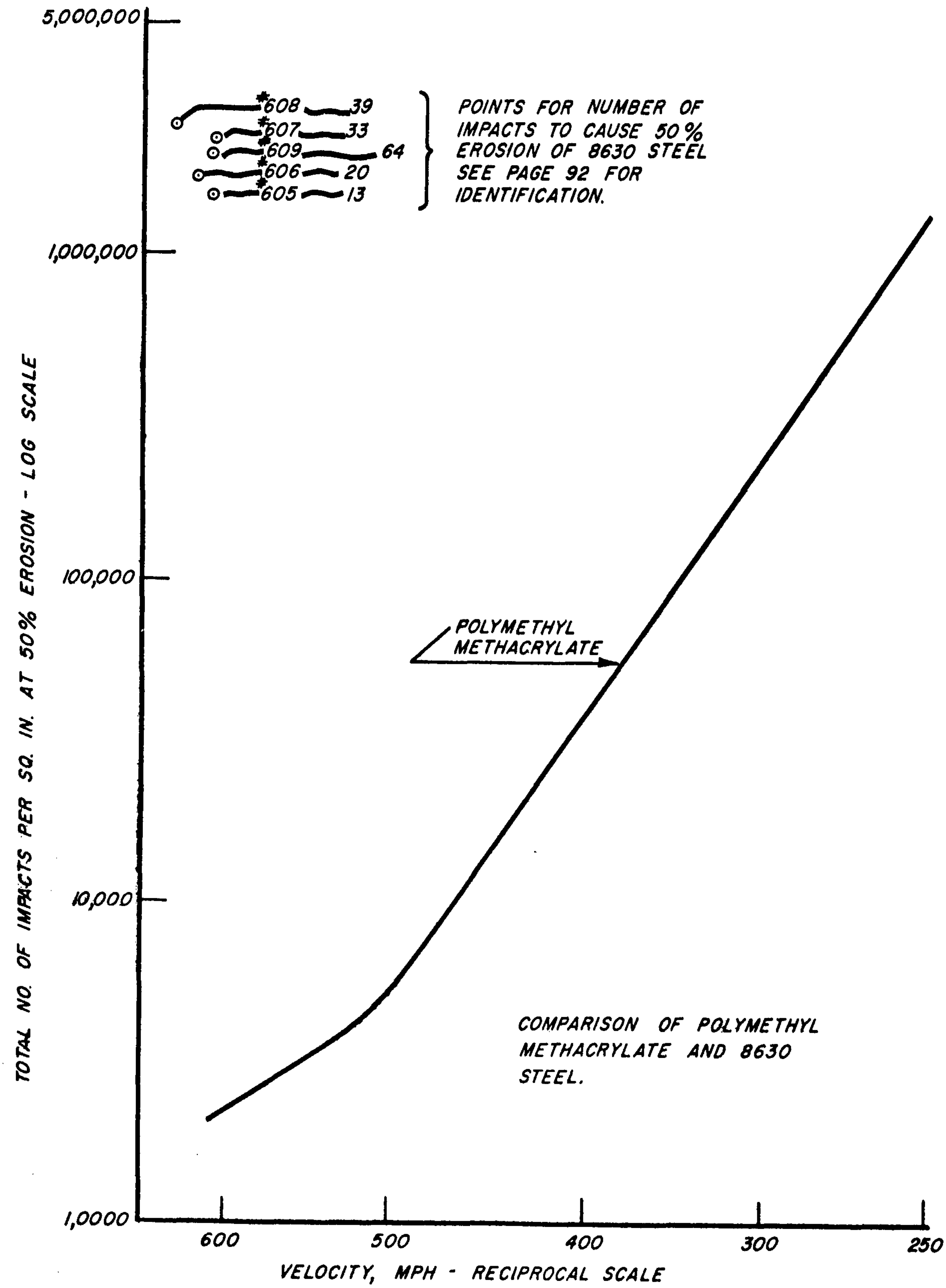
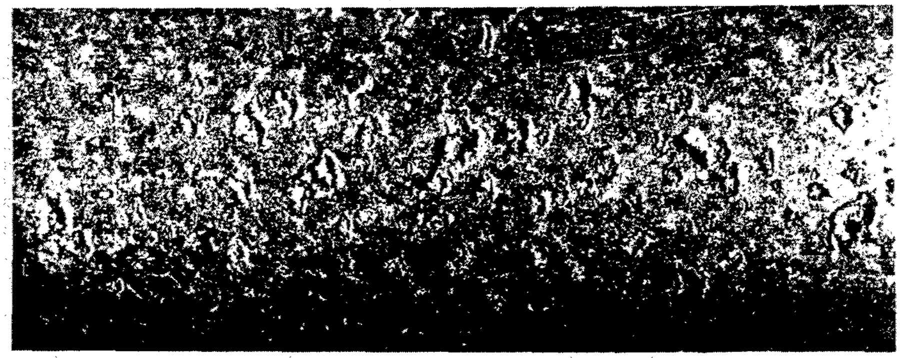


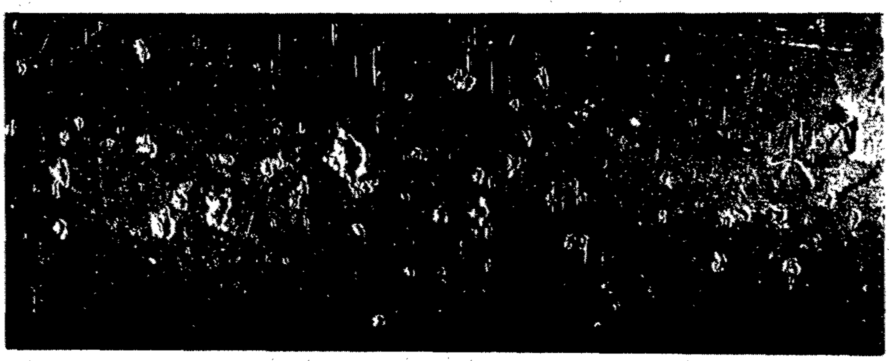
Figure 13 Rain Erosion Tests on Goodyear R14L-27-86 Coating

Figure 14 Comparison of Steel and Polymethyl Methacrylate

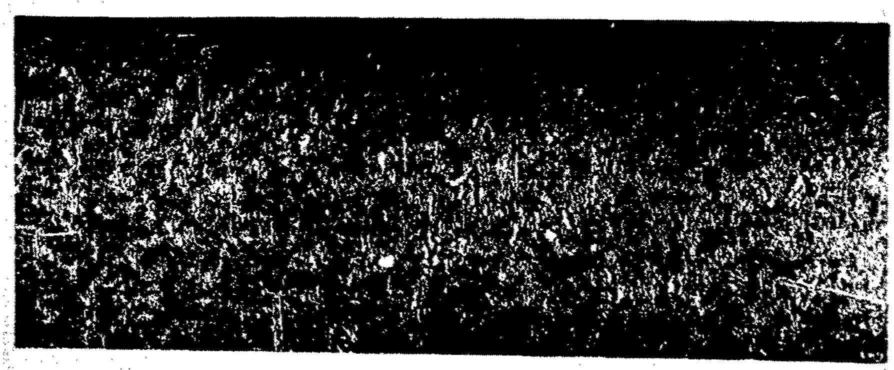




NO. 605 C-13 20 HRS.



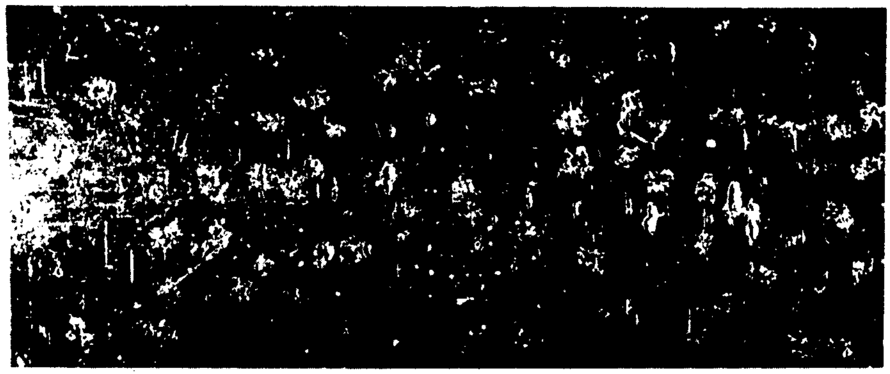
NO. 606 C-20 20 HRS.



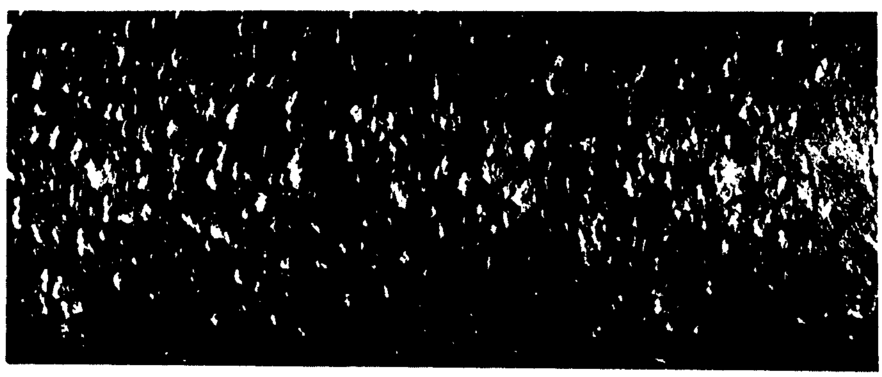
NO 607 C-33 30 HRS.

EROSION OF 8630 STEEL

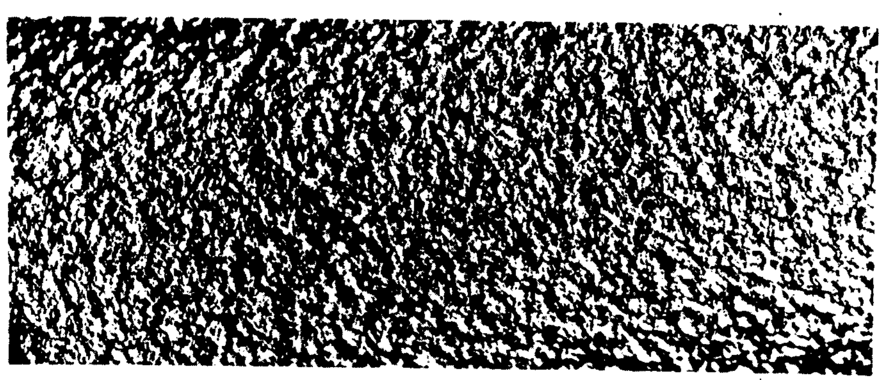
Figure 15 View of 8630 Steel Specimens After Erosion Test



NO. 608 C-39 30 HRS.



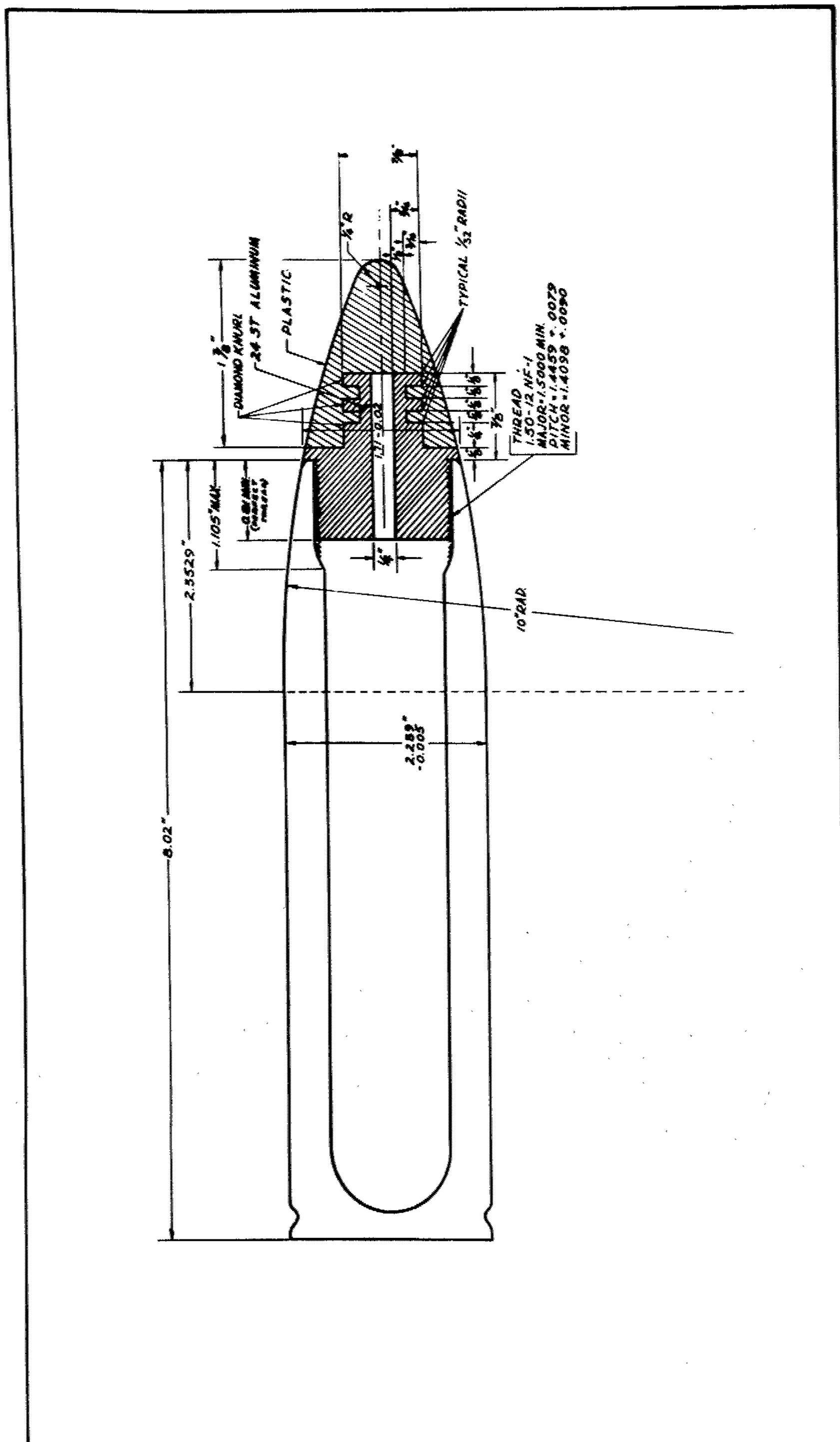
NO. 609 **CARBURIZED** C-64 30 HRS.



NO. 610 SHOT PEENED 8 HRS

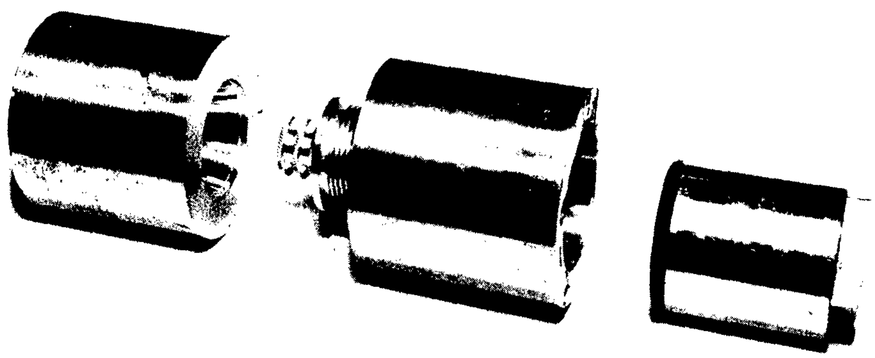
EROSION OF 8630 STEEL

Figure 16 View of 8630 Steel Specimens After Erosion Test



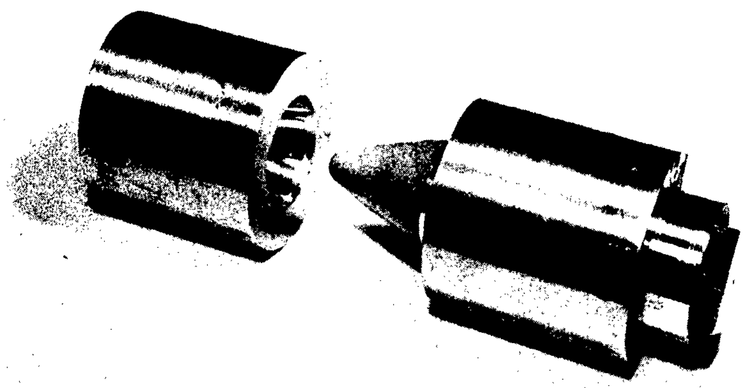
CROSS SECTION OF SHELL AND PLASTIC OGIVE

Figure 17 Dimensional View of Aluminum Insert and Plastic Ogive



EXPLODED VIEW OF OGIVE TRANSFER MOLD

Figure 18 View Aluminum Insert and Mold



TRANSFER MOLD AND PLASTIC OGIVE

Figure 19

RAIN EROSION OF COATINGS

PLASTIC OGIVE FOR 57MM SHELL

Figure 19 View of Plastic Ogive Molded on Aluminum Insert and Screwed into Upper Mold Body

Figure 20 View of High Speed End of Whirl Test Blade, Showing Erosion of Clips and Scale That Precipitated on Blade During High Speed Runs